Commentary

PHYSICS EDUCATION

PERHAPS the heraldic symbol of today is the Committee Couchant. Certainly any anthropological study of our age must give some attention to the committee parochial, the committee national, the committee international. There are several useful purposes which are served by committees; they can collect information and serve as a forum of exchange; they can co-ordinate and initiate new endeavour; they can deliberate and express an opinion. A committee is a poor means of directing and controlling action and as Lord BOOTHBY once commented, ' In any argument between a tank and a committee, I should back the tank every time '.

The first International Conference on Physics Education was held recently at UNESCO House in Paris during late July and early August. This was organized under the auspices of the International Union of Pure and Applied Physics and was attended by some ninety delegates representing twenty-eight countries and several agencies and organizations such as the International Atomic Energy Agency, the Organization for European Economic Co-operation (OEEC) and the United Nations Educational, Scientific and Cultural Organization (UNESCO). The problems are universal; the increasing demand for people trained in the physical sciences, the increased numbers seeking such training. And everywhere there is a clamant shortage of teachers. In many, indeed in most, countries there is something in the nature of a crisis.

An international conference of this nature has a very real advantage compared with other such conferences; there is a common and fundamental shared professional experience which cuts across the relatively trivial barriers of language and geography. The agreement among the members as to what they wanted to do was remarkable.

All fields of Physics Education were surveyed from the elementary to the post-doctoral. Sessions were held on ' Physics as part of general education ', ' The selection of students ', and the associated question of 'Examinations in physics', 'The work of the American Physical Science Study Committee', ' The place of practical work in the teaching of physics ', ' The teaching of physics to engineers, chemists, *etc.*', ' The teaching of mathematics ', ' The training of teachers ', ' The postgraduate training of physicists ', and ' The use of films and television in the teaching of physics '. Some forty-six illustrative and ' teaching ' films were shown and there was an exhibition of instruments and apparatus.

It was a busy, hard-working and harmonious conference. Indeed the most serious disturbance was that the UNESCO staff were upset that someone had forgotten to notify them that there was an exhibition of apparatus and equipment since they felt they would like to see it. The less industrialized countries discovered that some at least of their problems were universal and indeed that in some respects they were almost at an advantage in ensuring that due emphasis is given to the progress made in the present century. All students would have rejoiced to hear the views expressed on examinations.

Education in physics is, today, the basis of many professions. Children who wish to develop and build on the physics they studied at school may seek to do many different things. They may wish to become Electrical Engineers, Electronic Engineers, Communications Engineers, Mechanical Engineers, Heat Engineers, Materials Technologists, Glass Technologists, Nuclear Technologists—or plain ' Physicists '. The training is an intellectual, a professional and an industrial Pandora's Box. There is an expanding demand for men with an appreciation of a wide spectrum of practical arts who are ' trained as physicists '. The many differing fields of ' applied physics ' must not be forgotten, either in the early stages of physics education or in the later stages of professional training. Each of these is a professional study, a discipline, a career in itself and every profession has a right to consideration for the title of physicist.

It is difficult to estimate the value of a committee meeting; it is quite impossible to assess the value of such an international conference. The formal sessions were both informative and instructive, which is unusual. As always at international gatherings the opportunities for private exchange between members were unique and invaluable. The International Union of Pure and Applied Physics is to be congratulated on its initiative and the organizers on their hard work. More should be held and are likely to be held from time to time. Perhaps the most striking and sound conclusion of this conference was that physics education is a matter of providing opportunities to *learn* of which the teacher is most important. Sometime it would be useful to give attention to what a physicist is and establish criteria of entry into the profession.

Tercentenary of the Royal Society

A Description of the Celebrations

SIR CHARLES DARWIN

IN THE July number of *Research* Sir Edward SALISBURY briefly sketched the three hundred years of the history of the Royal Society. The celebrations of the tercentenary are now over, and it may interest the readers of *Research* to hear a little about them.

The central event was the meeting on Tuesday, 19 July in the Albert Hall. The hall was quite full and it was a really impressive ceremony. It began with a procession of something over three hundred of the Fellows of the Society wearing academic dress, followed by another procession composed of about two hundred and fifty foreign members and also official delegates from scientific institutions in Great Britain and abroad—bearers of addresses of congratulation, many wearing the academic robes of their own countries. Then came the Council of the Society together with former presidents and officers; and finally the President, Sir Cyril HINSHEL-WOOD, led in Her Majesty the Queen together with the Duke of Edinburgh, and the King and Queen of Sweden. At intervals during the ceremonies there was music, including a composition specially written for the occasion by Sir Arthur Bliss, Master of the Queen's Musick.

The proceedings fell into two parts. The Queen made a gracious speech, replied to by the President and followed by three short addresses of greeting to the Society by representatives of the University of Bologna, the French Academy and the Australian Academy. Next came the ceremony of formally admitting the King of Sweden who had recently been elected as a Foreign Member of the Society; this was carried out in the traditional manner—he signed his name in the book and the President admitted him with the customary formula. The King then gave a quite admirable short address to the Society.

The royal party were then escorted out of the hall by Sir Cyril Hinshelwood, though the Duke and the King and Queen of Sweden went into the Royal Box to witness the second part of the proceedings—the President's address. In this, after touching on the foundations of the Society and on some of its history, Sir Cyril gave some extremely interesting views about the functions of scientific academies and

their relations to the state, to the universities and to the community in general. He went on:

' An academy therefore is the natural body to provide for several vital things: non-commercial periodicals for the publication of discoveries, a measure of financial support for ideas still too embryonic to be of immediately obvious practical application, the mutual stimulus of association and discussion, and the immaterial reward of honour for intellectual achievement. Governments may act as patrons. They can and do solicit and receive the help of learned men, they favour and encourage enterprises which they judge to be timely, but they cannot provide for men of science the intangible yet powerful encouragement which comes from acceptance and election by their peers. The academy, if it maintains high standards of unquestioned impartiality, sets the tone throughout the scientific community, and its influence is felt in every quarter. It is no rival to government organizations or to industry, and should maintain the closest connections with them by electing into its number the leaders from both. Because men of action and men of authority esteem it an honour to be elected, the academy exerts its influence far beyond the confines of the learned world. The professional men of science hear of the needs of the state and of industry which in their turn are irrigated by the currents of scientific thought. The intercourse on terms of equality between the representatives of these different estates of the nation is like a sensitive nervous mechanism endowing the community which possesses it with capacities and potentialities realizable in no other way. The subtle coordinating action of an academy can no more be replaced by a bureaucratic organization or a system of economic incentives and deterrents than the intricately evolved biological controls of a living organism can be replaced by crudely devised mechanical appliances.'

Sir Cyril concluded by saying that though we cannot at all foretell the future, we may hope that the present general conditions will continue and that the Society will go on filling as usefully as in the past this particular niche in the organization of society.

The Albert Hall ceremony was the central occasion, but it was supplemented by many other meetings which gave pleasant opportunities to meet old friends and to make new acquaintances. There were receptions, the first given by Her Majesty's Government at Lancaster House, another by the University of London and one in the Guildhall given by the Lord Mayor, while the Society itself held a soirée on July 23rd in which a quite remarkable display of experiments was shown. Finally on the 26th there was the Tercentenary Banquet, attended by some 1100 people. The chief guest was the Prime Minister, who made an admirable speech describing the general relations of Government and the Society.

In addition to these general ceremonies and occasions, the week was filled by a long list of other things, including a number of lectures by experts and also visits to places of interest. The lectures dealt with a great variety of subjects, and it was impossible for anyone to attend more than a few of them. For example, on the side of the physical sciences, Professor A. C. B. LOVELL described the progress in radio astronomy, Professor C. F. POWELL dealt with cosmic rays, while Sir Christopher HINTON described the development of atomic power stations, to which he has himself made important contributions. This lecture was interesting to the scientists in that economics were discussed as well as pure science, giving it a refreshing character not always found in scientific lectures. On the biological side there were, among others, a brilliant lecture on genetics by Professor C. D. DARLINGTON and one on the newer branches of biophysics by Professor A. L. HODGKIN.

Of the visits perhaps the two chief ones were those to Oxford and Cambridge. At Oxford Wadham College was pre-eminent, because John Wilkins was Warden there in the pre-natal period of the Society when the ' Invisible College ' met under his presidency. At Cambridge there was an exhibition of many early papers connected with the Society, including the originals of several letters from and to Newton. Other visits included the Royal Observatory at Hurstmonceaux, the Atomic Energy Establishment at Harwell, the John Innes Horticultural Institution, the National Physical Laboratory, Newton's home at Woolsthorpe, Down House, the Whipsnade Zoological Park, many industrial research laboratories, and all the London museums.

Altogether it made a very full week, and the only regrets that those who attended the celebrations could feel was that there were too many things that they would like to have seen which the clash of rival entertainments made impossible.

Charles II.
(*Courtesy Royal Society*)

Royal Society Books
The Royal Society, its Origins and Founders
Sir HAROLD HARTLEY, F.R.S. (*Ed.*)
(*275 pp. 35s*)

A Brief History of the Royal Society
E. N. DA C. ANDRADE, F.R.S.
(*275 pp. 35s and 128 pp. 8s 6d*)

Published by The Royal Society, Burlington House

IN CONNECTION with the celebrations of the Tercentenary of the Royal Society of London, two small books have been published. ' On 28 November, 1660, twelve members of the group who had been meeting each week at Gresham College in the City of London after lectures by Christopher Wren decided to form a society for the improving by experiment of natural philosophy '. The first of these books, edited by Sir Harold HARTLEY contains twenty-five contributions by various distinguished authors including twenty-two biographical articles one of which is devoted to Charles II, the founder and first patron; other articles are on each of the twelve founders.

The brief history by E. N. da C. ANDRADE surveys the background and the growth and development of the Society to the present day. Both are lavishly illustrated and can be cordially commended not only because they provide a background to the recent celebrations but since they provide insight into the growth of a remarkable, influential and peculiarly British institution. G.K.T.C.

BUILDERS AND FILLERS
IN HOUSEHOLD DETERGENTS

N. PILPEL

An account is given of the builders, fillers and other materials which, for technical and economic reasons, are incorporated in household synthetic detergents.

MOST household synthetic detergents* contain, in addition to the surfactant, *i.e.* the surface active agent, other chemicals which, in many cases, account for more than three quarters of the contents of the carton or packet. While some of these (the fillers) serve little purpose except as diluents for reducing costs, others (the builders) play an essential part in the actual removal and suspension of dirt. It would have been impossible to develop the synthetic surfactants for domestic washing and for many industrial purposes had it not been discovered how certain of their properties could be modified by blending them with these other materials.

It is the purpose of this article briefly to review their historical development, to explain their economic importance and to describe recent work that has been done on elucidating the way in which they assist in detergent action.

Historical

The use of builders in soap manufacture goes back over a hundred years and J. N. VON FUCHS is said to have suggested incorporating sodium silicate into soap as early as 1825. By the middle of the century this material was being fairly widely used; for example in 1867 Gossage's were selling approximately sixty tons of silicated soap a week[1].

Sodium carbonate, likewise, was used during the second half of the nineteenth century and the soap powders that were introduced in the 1860s and 1870s contained, in some cases, as much as 35 per cent of this ingredient. Other builders that were incorporated in soap from about 1900 included trisodium phosphate, sodium bicarbonate, sodium sesquicarbonate and sodium hexa*meta*phosphate (Graham's salt).

The introduction of synthetic detergents, which started in this country in the late 1930s, was at first relatively unsuccessful and in the light of subsequent developments it is now clear that one reason is that a combination of builders that gives good results with a soap is rarely suitable for a synthetic surfactant. Moreover, the purpose for

* In this article 'synthetic detergent' or 'syndet' refers to products based on synthetic surface active agents as opposed to those based on soaps.

which a particular product is to be employed largely determines its builder requirements. In general the greater the amount of solid dirt that it has to remove, the more building it will need. But the nature of the dirt, the quality of the water and the type of material being washed also play a part.

Synthetic detergent products sold in the U.K. before 1939 contained no builders. On the one hand there were the soapless shampoos, consisting essentially of the surfactant, perfume and either water or a filler such as sodium sulphate; and on the other hand a very limited number of light duty powders were based on sulphated fatty alcohols and contained up to sixty five per cent of sodium sulphate. But sales of both were small and it has been estimated[2] that the pre-war consumption of syndets of all types in this country was less than five hundred tons a year.

During the war relatively little development work was possible on syndets for domestic purposes and the products that were sold to eke out the soap ration were, on the whole, of a poor quality.

Two leading chemical firms had started bulk production of synthetic detergents in 1942 and 1943. These were available on the domestic market in the form of aqueous solutions, but they were suitable only for light duty washing and were, moreover, considerably more expensive than soap. There were a number of dishwashing powders and cleansers which contained over 90 per cent of a mixture of carbonates, bicarbonates, phosphates, silicates and sulphates with relatively small amounts, 3–8 per cent, of a surfactant. These were intended for removing grease from crockery and for preliminary soaking of soiled articles of clothing. But they were crude products, harsh on the hands, subject to deterioration on storage and of limited application so that although sales reached forty four thousand tons a year (as marketed) in 1948, this was only because soap was in such short supply.

The first properly built syndet powders did not come onto the United Kingdom market in any quantity until the early 1950s. This was due both to a lack of suitable manufacturing equipment and to a
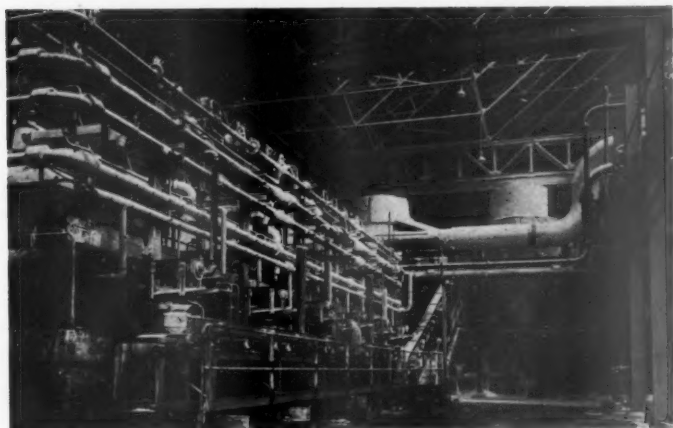
*Figure 1. Sodium tripolyphosphate plant (courtesy Albright and Wilson)*

shortage of some of the necessary ingredients. In particular there was a severe shortage of complex phosphates which was only relieved when Marchon Products (now Albright and Wilson) built new factories for converting phosphate rocks into sodium tripolyphosphate, tetrasodium pyrophosphate and the other complex phosphates which are employed today in nearly all synthetic detergent formulations.
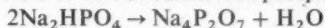
Builders

Phosphates

The phosphates used in syndets are of three kinds.

First, and by far the most important, is sodium tripolyphosphate. This is prepared[3] by heating a mixture of disodium *ortho*phosphate and mono-sodium *ortho*phosphate at a temperature above 300°C when the following reaction takes place:

$$2Na_2HPO_4 + NaH_2PO_4 \rightarrow Na_5P_3O_{10} + 2H_2O$$
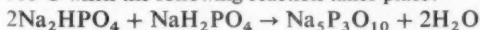
The commercial product is anyhdrous. Production is estimated at more than 50,000 tons a year of which about 35,000 tons is used in detergents (*Figure 1*).

Next is tetrasodium pyrophosphate. The method in this case is to heat disodium *ortho*phosphate

$$2Na_2HPO_4 \rightarrow Na_4P_2O_7 + H_2O$$

Although a certain amount had been used as a builder in soap products before the war, it was not until the 1950s that appreciable quantities of tetra-sodium pyrophosphate were incorporated into synthetic detergent products and consumption is now somewhere in the region of 5000 tons a year.

Finally there is a range of glassy, polymeric phosphates of which sodium hexa*meta*phosphate

(Graham's Salt) is the most widely used. This is made by heating monosodium *ortho*phosphate:

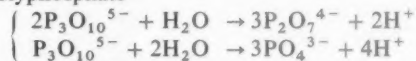$$nNaH_2PO_4 \rightarrow (NaPO_3)_n + nH_2O$$

At present a typical, all purpose syndet powder contains approximately 35 per cent of phosphates, but the proportions of the three kinds are frequently altered. For example in December 1950 a well known product contained 34 per cent phosphates of which 80 per cent was sodium tripolyphosphate and 20 per cent was tetrasodium pyrophosphate. But in January 1954, the phosphate was entirely sodium tripolyphosphate and was increased to 40 per cent[3].

In their application to syndets the three kinds of phosphate can be distinguished in a number of ways. Of considerable importance is their ability to resist hydrolysis since this determines the shelf life of any product in which they are incorporated. Sodium tripolyphosphate, pyrophosphate and hexa*meta*-phosphate are all converted by water into the *ortho*-phosphate. This process, which is illustrated below, is controlled by such factors as the temperature and pH of the medium[4] but in general the pyrophosphate hydrolyses more slowly than the tripolyphosphate, which is more stable than the glassy phosphates.

Pyrophosphate

$$P_2O_7^{4-} + H_2O \rightarrow 2PO_4^{3-} + 2H^+$$

Tripolyphosphate

$$2P_3O_{10}^{5-} + H_2O \rightarrow 3P_2O_7^{4-} + 2H^+$$
$$P_3O_{10}^{5-} + 2H_2O \rightarrow 3PO_4^{3-} + 4H^+$$

Hexa*meta*phosphate

$$2PO_3^{-} + H_2O \rightarrow P_2O_7^{4-} + 2H^+$$
$$PO_3^{-} + H_2O \rightarrow PO_4^{3-} + 2H^+$$

The sequestering powers of the three phosphates for calcium, magnesium and other ions present in the washing water also differ considerably, *Figure 2*[5]. This ability of complex phosphates to hold clays, pigments and other finely divided solids in the form of suspensions in water is an essential requirement for efficient washing and work has been done in recent years to elucidate in detail the mechanisms of the process.

It appears that when a syndet is used with hard water, a direct chemical reaction takes place between the phosphate builders and calcium and magnesium ions. For sodium tripolyphosphate and calcium the reaction can be written

$$Na_5P_3O_{10} + Ca^{++} \rightarrow Na_3[CaP_3O_{10}] + 2Na^+$$
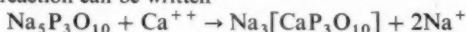
The resulting complex is soluble in water and the extent to which the reaction proceeds can therefore be measured by the amount of phosphate needed to clarify a standard soap solution in water of known hardness. Now many solid soils contain calcium or magnesium compounds which are normally insoluble in water but which are converted into the soluble sodium complexes by the phosphate. Thus the surface of the soil becomes hydrophilic and this enables it to remain dispersed in the water with little tendency to aggregate or deposit.
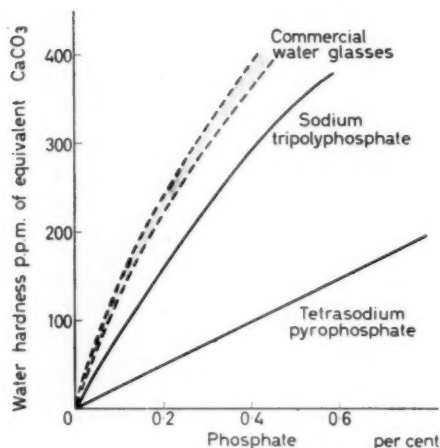

Figure 2. Amount of phosphate used in water softening at 25°C. (VAN WAZER and CALLIS[5]. Courtesy Chem. Rev.)

But besides this essentially chemical mechanism there are other ways in which phosphates assist in a washing process.

Grease or solid particles of dirt which have been displaced from a surface during the first stage of washing may be held in the water either in the form of an emulsion (in the case of grease) or in the form of a dispersion (in the case of solid particles) or in the form of a solution[6]. In the emulsified or dispersed states the droplets or particles of soil are relatively large—between about 0.1μ and 100μ in diameter and are surrounded by an oriented layer of the surfactant as shown in *Figure 3*. In the dissolved state the soil particles are smaller, $< 0.01 \mu$ and are accommodated within the micelles of the surfactant molecules.

The ability of the water to hold the soil is controlled very largely by the mechanical strength of the oriented film of surfactant which surrounds each particle or droplet of dirt. On the other hand the amount of soil that is dissolved depends, amongst other factors, on the sizes of the surfactant micelles. The strength of the film is considerably increased when phosphates, and to a lesser extent silicates, are present due to these reducing the electrostatic repulsive forces which would normally tend to disrupt the film. At the same time these electrolytes cause the micelles to increase in size[7]. Both mechanisms thus contribute to an increased retention of dirt.

Experiments have been made recently to measure this increase quantitatively. JAYSON[8] and DURHAM and CAMP[9], for example, have shown that although the rate at which fat soiled cotton is wetted by a syndet solution is decreased, the efficiency of soil removal is approximately doubled when 0.2 per cent of $Na_4P_2O_7$ or $Na_5P_3O_{10}$ is added to the washing water. Various techniques have been developed for following the cleaning of a fabric during washing and these include measurements of light reflectance[10] and light absorption and scattering[11].

Silicates

Sodium silicate, in a variety of forms, is employed as a builder in syndets and a typical powder contains approximately 10 per cent of sodium silicates. The various forms are distinguished by the ratio of SiO_2 to Na_2O present in the molecules: thus

Sodium *ortho*silicate Na_4SiO_4
    has an SiO_2/Na_2O ratio of 1/2
Sodium *meta*silicate $Na_2SiO_3.5H_2O$
    has an SiO_2/Na_2O ratio of 1/1
Sodium *sesqui*silicate $Na_3HSiO_4.5H_2O$
    has an SiO_2/Na_2O ratio of 2/3
while the glassy silicates or water glasses have an SiO_2/Na_2O ratio which usually lies between 1.5 and 3.8. The most usual method of manufacturing these silicates is to fuse sand with sodium carbonate in the required proportions.

Traditionally it had been the practice in soap manufacture to use silicates with a relatively high SiO_2/Na_2O ratio, in the neighbourhood of about three, but over the last twenty years or so there has been a tendency to use the more alkaline forms and sodium *meta*silicate in particular is now widely employed.

Silicates act in detergent processes in a very similar manner to phosphates[12]. Like phosphates they have a stabilizing effect on surfactant films, they increase solubilization of soil by increasing the size of the surfactant micelles and they complex with the salts of heavy metals such as iron and copper which might otherwise cause discolouration or staining. An additional function is to regulate the pH of the synthetic detergent blend and in particular to act as a buffer, *i.e.* to maintain the pH of the solution approximately constant when acids or alkalis are present. In this respect sodium *meta*silicate is markedly superior to sodium bicarbonate or alkaline phosphates.

But besides these functions silicates also have an important influence on other properties of syndet blends. Many surfactants have a corrosive effect on metals such as copper, aluminium, tin, steel *etc*.[13,14], an effect which is enhanced by the presence of complex phosphates, particularly unless the water is kept continuously agitated. Alkali silicates, however, are effective corrosion inhibitors[15], due, apparently, to their tendency to deposit onto the products of corrosion to form a protective layer. Their presence in the blend thus prevents damage to cooking utensils, plumbing, washing machines and metallic parts.

Silicates improve the textural qualities of soap and syndet powders by making them less friable. This is of considerable importance during spray drying where the objective is to produce the syndet as a granulated, free flowing powder. Blends from which the silicates have been omitted do not granulate satisfactorily and large amounts of wasteful dust are produced, both in the manufacturing plant and in the final product. Finally silicates improve the storage characteristics of syndets by reducing absorption of moisture which would otherwise result in clogging.

Sodium Carboxymethyl Cellulose

NaC.M.C. accounts for 1–2 per cent of a syndet powder. It was first developed in Germany in the late 1930s and is now also produced in the United Kingdom (*Figure 4*). It is made by treating cotton linters or wood pulp with caustic soda and sodium monochloracetate[18] and the reactions can be represented by
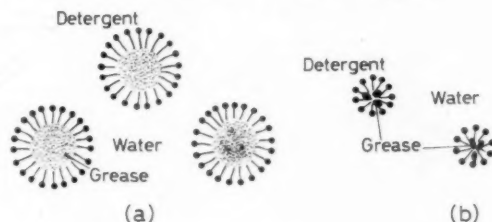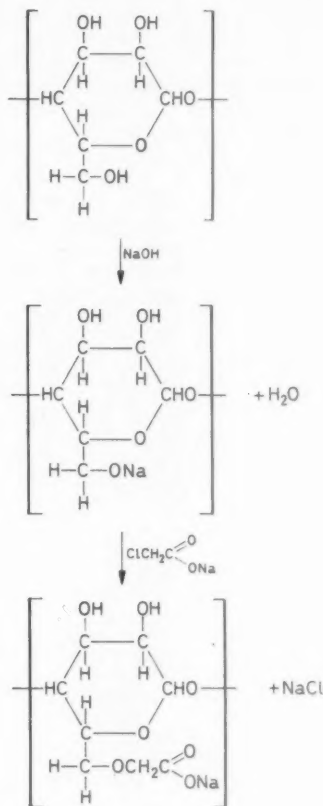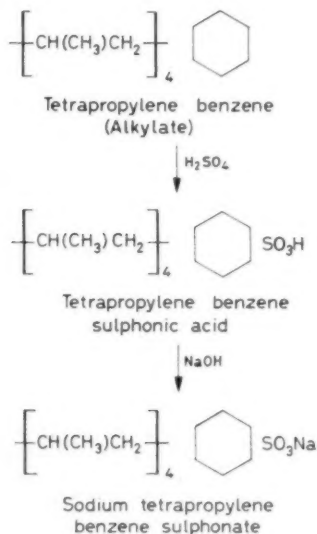

Figure 3. (a) *Grease emulsified by detergent;* (b) *grease dissolved by detergent*

Most of the grades which are used in syndets have between 0·4 and 0·8 hydroxyl groups substituted per cellulose unit and the degree of substitution controls the viscosity and solubility of the material in water.

The function of the sodium carboxymethyl cellulose is to increase the soil suspending powers of the syndet and in particular to prevent redeposition of soil onto a washed article. While the phosphate and silicate builders do this effectively, weight for weight NaC.M.C. is more efficient. However, at the present time NaC.M.C. costs approximately three times as much as the phosphate builders and between five and ten times as much as the silicate builders so that from an economic point of view only relatively small amounts can be employed.

Sodium Sulphate

Between them the builders and the surfactant account for approximately seventy per cent of a typical heavy duty synthetic detergent. The bulk of the remainder, about twenty-five per cent, is sodium sulphate. However, unlike the other ingredients this plays very little part in the washing process. It has some effect on the texture and appearance of the blend, but this is incidental and primarily the sodium sulphate serves as a cheap filler. It is formed as a by product in the sulphonation process[16], whereby *Alkylate*, which is obtained from the oil companies, is converted by the syndet manufacturers into the sodium salt of the alky aryl sulphonic acid.

$$\left[CH(CH_3)CH_2\right]_4 \bigcirc$$

Tetrapropylene benzene
(Alkylate)

↓ H_2SO_4

$$\left[CH(CH_3)CH_2\right]_4 \bigcirc SO_3H$$

Tetrapropylene benzene
sulphonic acid

↓ NaOH

$$\left[CH(CH_3)CH_2\right]_4 \bigcirc SO_3Na$$

Sodium tetrapropylene
benzene sulphonate

This product is the most generally employed surfactant in this country at the present time.

The mixture of the surfactant and sodium sulphate is blended directly with the other ingredients, thereby avoiding the expense of an extra purification process. Additional sodium sulphate, up to the level of 25 per cent, is incorporated during blending and this helps further to reduce the cost of the product[17].

There remains in a typical synthetic detergent powder about 5 per cent of other ingredients.

Chemical Bleaching Agents

Many of the synthetic detergents contain between 2 and 5 per cent of chemical bleaching agents of which the most widely used is sodium perborate. Sodium percarbonate has also been employed at various times. Perborates and percarbonates evolve oxygen when dissolved in hot water and this has a whitening effect on fabrics such as cotton, which otherwise acquires a greyish tinge after repeated washing. Some of the earlier soap and syndet products contained sodium hypochlorite as the bleaching agent. Although this is still used in formulations for commercial laundries[19], the perborates and percarbonates are milder, cause less damage and tendering of fabrics, are less harmful to some of the resin finishes used on cotton and rayon articles and are, in addition, less irritating to the skin of the user.

However, their employment has resulted in a number of technical problems during manufacture of the syndet. Being unstable at high temperatures they cannot be incorporated into the blend before it is spray dried, but have to be added after the weathering stage[17]. This involves physical mixing which is not entirely satisfactory due to the relatively big difference in density between the per compound and the granulated blend.

Attention is turning to ways of overcoming the difficulty; one interesting proposal is that the detergent slurry should be sprayed first into a cool gas stream in such a way as to produce hollow conical granules into the centres of which the bleaching agent could be injected. In this way the heat sensitive material would be shielded when the granules subsequently encounter the hot gas stream[20]. So far, however, the technique has not been adopted on a commercial scale.

Optical Whiteners

In contrast to the chemical bleaching agents, optical whiteners, which are also used, rely for their effect on a physical process, namely the absorption of ultraviolet light and its re-emission at a wavelength in the region of 450 mμ which is visible to the eye.

Optical whiteners were described by P. Krais[21] in 1929 and were first marketed just before the last war. They have been used on a commercial scale in this country since the mid-1950s.

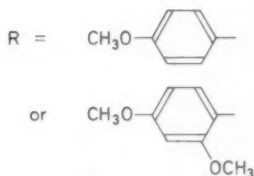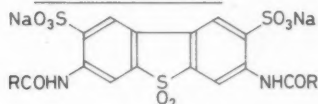At the present time six main types are in use[22]:

or cotton, whether it has been given a surface finish to make it drip dry, flame proof and so on.

Various problems have had to be overcome to make the optical whiteners acceptable for general use. For example, if an article is repeatedly washed
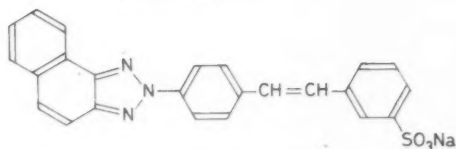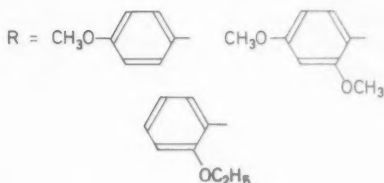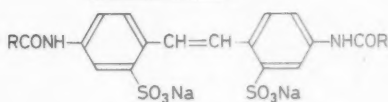
Triazinylstilbenes
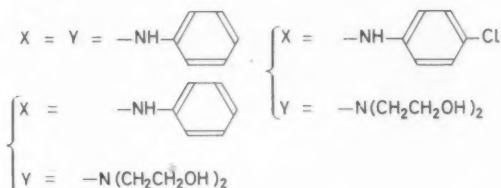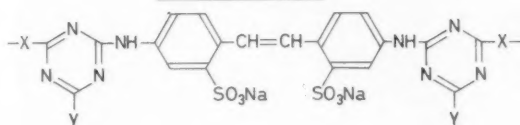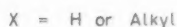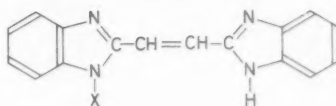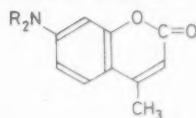
Aroylstilbenes

These differ in their applicability, the amino coumarins being more suitable for light duty washing, the triazoles for use with anionic syndets and the triazinyl- and aroylstilbenes for general washing, though the results obtained also depend to a considerable extent on the nature of the article being washed, e.g. whether it is made of nylon, rayon

with inadequately mixed syndet solution, the whitener may be deposited unevenly over the article resulting in a patchy appearance or even a change of colour. Moreover it has been estimated[1] that the cost of the raw materials in a blended syndet is raised by about 5 per cent if 0·1 per cent of an optical whitener is incorporated.

Despite this they have considerable sales appeal and most of the syndets employed for domestic purposes in this country now contain about 0·1 per cent of optical whiteners.

Sequestering Agents

Sequestering agents such as ethylene diamine tetraacetate (E.D.T.A.) are sometimes added to syndets to improve their solubilizing power for salts of iron and heavy metals which might otherwise cause staining. They are commercially available in the form of the di-, tri- and tetrasodium salts which are prepared by reacting ethylene diamine with chloracetic acid, followed by neutralization with soda[24]

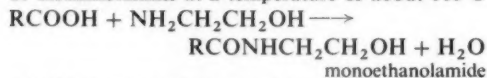$$NH_2C_2H_4NH_2 + 4CH_2ClCOOH \longrightarrow$$

$$\begin{array}{c} HOOCCH_2 \\ \diagdown \\ HOOCCH_2 \diagup \end{array} NC_2H_4N \begin{array}{c} \diagup CH_2COOH \\ \diagdown CH_2COOH \end{array} + 4HCl$$

$$\Big\downarrow NaOH$$

$$\begin{array}{c} NaOOCCH_2 \\ \diagdown \\ NaOOCCH_2 \diagup \end{array} NC_2H_4N \begin{array}{c} \diagup CH_2COONa \\ \diagdown CH_2COONa \end{array}$$

Tetrasodium E.D.T.A.
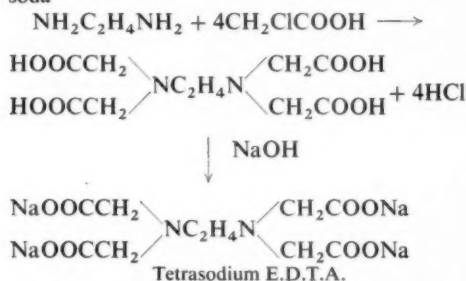
The amounts used are generally less than 1 per cent.

Foam Boosters

Foam boosters are added to syndets in small amounts to increase and stabilize the foam that they produce. Compounds that are employed for this purpose include mono- and diethanolamides of naturally occurring fatty acids. They are prepared by heating the acids or their esters with ethanolamine or diethanolamine at a temperature of about 160°C

$$RCOOH + NH_2CH_2CH_2OH \longrightarrow$$

$$RCONHCH_2CH_2OH + H_2O$$
monoethanolamide

$$RCOOH + NH(CH_2CH_2OH)_2 \longrightarrow$$

$$RCON(CH_2CH_2OH)_2 + H_2O$$
diethanolamide

The above two compounds are themselves non-ionic surfactants and therefore assist in the washing process in their own right. But this is incidental and the main function of the foaming agent is to satisfy the public's preference for products which produce a good lather and to some extent indicate the rate at which the detergent is being used up during washing.

The actual mechanism of foam production and stabilization will not be elaborated on in this article, since the topic has already been reviewed[23]. Suffice to say that in the case of the two compounds now being considered their molecules, being nonionic,
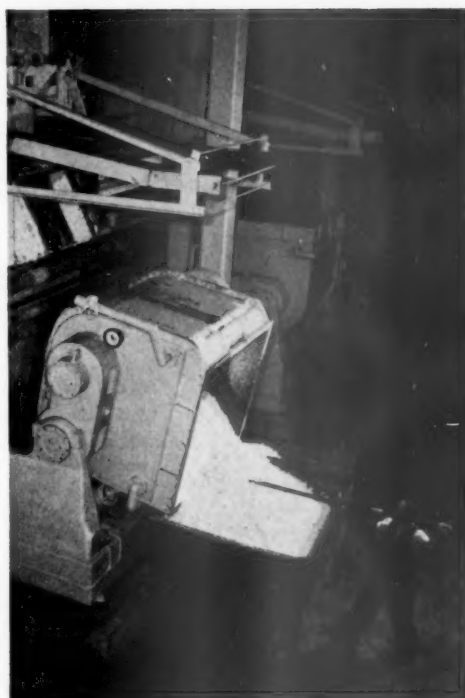

Figure 4. Production of sodium carboxymethyl cellulose; emptying crumbs of alkali cellulose from a grinder (courtesy Courtaulds Ltd)

are able to penetrate between the oriented molecules of the anionic surfactant which enclose each air bubble in the liquid. There is a decrease in the surface tension and an increase in the surface viscosity and elasticity and this results in a good foam with high stability.

Built Liquid Syndets

So far the emphasis in this article has been on syndets which are sold in the form of blended powder and little has been said about liquid synthetic detergents. While these have been widely available since 1944, until recently liquid syndets had always been considered essentially light duty products, suitable for washing the hands, dishes and lightly soiled fabrics, but unsuited to the heavy wash.

The earlier liquid syndets consisted almost entirely of a surfactant, with a little ammonium chloride, perfume, glycerine and water. The newer products contain phosphate and silicate builders,

solubilizing agents, opacifying agents, soil suspend-
ing agents and fluorescent dyes and are comparable
with the blended powders in regard to performance.

The problems which arise in formulating heavy
duty liquid syndets are basically different from
those associated with the powdered products. One
of the biggest difficulties is to obtain sufficiently
concentrated solutions of the detergent in water to be
economic for packaging and transport and yet
remain stable during storage, without one or more
of the ingredients separating out. Although incor-
poration of solvents such as ethyl alcohol and water
soluble materials such as urea are of assistance, the
problem is solved primarily by replacing sodium
compounds by the corresponding potassium com-
pounds, which are very much more soluble in water,
Figure 5. In this way products containing up to 50
per cent by weight of solids can be prepared without
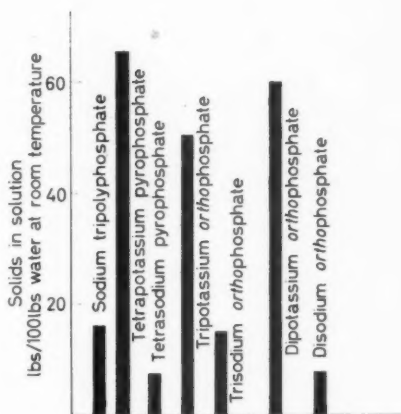separation of phases.

Figure 5. Solubility of phosphates (after VAN
WAZER *and* LISS)

Tetrapotassium pyrophosphate has been more
widely used as a builder in liquid syndets than the
other complex phosphates because of its greater
stability towards hydrolysis. It has similar sequester-
ing powers to tetrasodium pyrophosphate and
probably assists the washing process in a similar
manner. But its price is approximately double that
of its sodium analogue. Typical heavy duty liquid
syndets contain between ten and twenty five per
cent of tetrapotassium pyrophosphate.

Potassium silicates, however, have only been
employed as builders for experimental purposes and
the new liquid syndets contain, instead, the glassy
sodium silicates which have already been described.
These are preferred to the crystalline silicates,
Na_4SiO_4, $Na_2SiO_3.5H_2O$ and $Na_3HSiO_4.5H_2O$
because of their greater solubility in water.

Some metathesis occurs between the sodium
silicate and the tetrapotassium pyrophosphate[25], but
precipitation of the resulting tetrasodium pyro-
phosphate is inhibited by keeping the silicate
content of the syndet below 15 per cent and its pH
in the region of ten. The small amount of precipi-
tation that occurs in spite of this is masked by
incorporating a trace of an opacifying agent, such as
zinc stearate, which gives the liquid an attractive,
translucent appearance.

References

[1] CORLETT, W. J. *The Economic Development of Deter-
gents*. London: Duckworth. 1958
[2] PUPLETT, P. A. R. *Synthetic Detergents*. London:
Sidgwick & Jackson. 1957
[3] Anon. *Chem. Engng* (1954) **61**, 132, 320
[4] CAMPBELL, D. O. and KILPATRICK, M. L. *J. Amer.
chem. Soc.* (1954) **76**, 893
[5] VAN WAZER, J. R. and CALLIS, C. F. *Chem. Rev.*
(1958) **58**, 1011
[6] KLEVENS, H. B. *Chem. Rev.* (1950) **47**, 1
[7] MANKOWICH, A. M. *J. Phys. chem.* (1954) **58**, 1027
[8] JAYSON, G. G. *J. appl. Chem.* (1959) **9**, 422, 429
[9] DURHAM, K. and CAMP, M. *Proc. 2nd Int Congr.
Surface Activity*. London: Butterworths. (1957) 245
[10] SHUTTLEWORTH, T. H. and JONES, T. G. *Proc. 2nd.
Int. Congr. Surface Activity*. London: Butterworths.
(1957) 279
[11] WAGG, R. E. *Proc. 2nd Int. Congr. Surface Activity*.
London: Butterworths. (1957) 62
[12] VAIL, J. G. *Soluble Silicates*. Vols. 1 and 2. New
York: Reinhold. 1952
[13] HOLMES, H. and ROSS, T. K. *J. appl. Chem.* (1951) **1**,
158; (1952) **2**, 520
[14] ROSS, T. K. *J. appl. Chem.* (1955) **5**, 10
[15] EVANS, U. R. *Corrosion and Oxidation of Metals*.
London: Edward Arnold. 1960, 163
[16] BIRCH, S. F. *J. Inst. Pet.* (1952) **38**, 69
[17] PILPEL, N. *Soapless Detergents*. Unilever Educational
Series
[18] HADER, R. N., WALDECK, W. F. and SMITH, F. W.
Industr. Engng Chem. (1952) **44**, 2803
[19] NIVEN, W. W. *Industrial Detergency*. New York:
Reinhold. 1955
[20] RAPHAEL, L. *Mfg Chem.* (1957) **18**, 240
[21] KRAIS, P. *Melliand Textilber.* (1929) **10**, 468
[22] VILLAUME, F. G. *J. Amer. Oil Chem. Soc.* (1958) **35**, 558
[23] PILPEL, N. *Research, Lond.* (1955) **8**, 330
[24] SCHWARZ, A. M., PERRY, J. W. and BERCH, J. *Surface
Active Agents and Detergents*. New York: Inter-
science. 1958
[25] MCCUTCHEON, J. W. *Soap and Sanit. Spec.* (1957) **33**, 43

MODERN IDEAS ON THE MECHANICAL POLISHING OF METALS

L. E. SAMUELS

Australian Defence Scientific Service, Defence Standards Laboratories, N.S.W. Branch, Sydney, Australia

A widely accepted view is that mechanical polishing occurs by a process of surface flow, producing a drastically-altered, amorphous-like layer known as the Beilby layer. However, evidence obtained recently indicates that this is not so, at least when metals are polished by the use of fine abrasives. The new evidence indicates that polishing occurs primarily by cutting, producing a crystalline, but plastically deformed surface.

It is a common practice both in industry and in the laboratory to brighten metal surfaces by rubbing them against a series of successively finer abrasives, and it is most noticeable that the surface finish achieved depends largely upon the way in which the abrasive is used. For example, a certain fine abrasive when cemented to cloth or paper backing might produce a surface which contains obvious scratches and which appears dull because it scatters light diffusely; this may be called an abraded surface. On the other hand, the same abrasive when used as a slurry on a soft cloth pad, as in metallographic laboratory practice, or with wax on a rotating cloth disk or mop, as in industrial finishing practice, may produce a surface which is bright and mirror-like, reflecting light specularly. This is called a polished surface.

The considerable difference in appearance between abraded and polished surfaces has resulted in speculation as to whether there is any fundamental difference between the two and in the way in which they are formed. The question is not solely one of academic interest, since the results of laboratory experiments and the service performance of industrial components could often be critically sensitive to surface structure.

The Classical Theories of Polishing

The earliest view, which was supported in particular by Sir William Herschel, was that the difference between the two types of surface is only one of degree. That is, both occur by the cutting of grooves or scratches but the scratches on polished surfaces are much narrower and shallower than in the case of abraded surfaces. The requirement for specular reflection is only that the scratches be spaced at less than the wavelength of the incident light. Doubts on this simple view were first expressed by Lord Rayleigh[1] and were followed by the development of a radically different theory by Sir George Beilby[2], the latter soon becoming the accepted theory of polishing.

Beilby's proposal was that polishing occurs by a process in which material is smeared across the surface to fill in the pre-existing irregularities. The surface thus becomes covered with a smooth layer of material which is thought to be ' amorphous-like ', or ' liquid-like ', at least in the sense that it has lost its obvious crystalline structure and properties. This layer has come to be known as the *Beilby layer*, and modern estimates place its thickness at 50–100 Å on surfaces of the type being considered. The theory therefore proposes not only that there is basic difference between the mechanisms by which abrasion and polishing occur, but also that there is a drastic difference in the nature of the resultant surfaces.

An important refinement to the theory was later made by Bowden and Hughes[3] who suggested a mechanism by which the surface smearing or flow occurs. Their suggestion was that polishing is a thermally-activated process; that is that the asperities in the original surface are melted locally when an abrasive particle rubs past them and the molten material is deposited in adjoining depressions, so gradually filling them and levelling the surface. They further proposed that, due to the rapid chilling, the redeposited molten material solidifies in an amorphous-like condition, and then constitutes the Beilby layer.

However, a series of investigations carried out in recent years[4-7] has led the present author to revert to the original view held by Herschel that polishing, at least in some circumstances, is a fine cutting operation. This article will review briefly the evidence concerned and will summarize the information obtained on what is thought to be the true nature of the polished surfaces.

Polishing a Cutting Process

It is clear from the writings of RAYLEIGH[1] and BEILBY[2] that one of the main reasons why a new mechanism of polishing was sought was that no fine structure could be discerned in polished surfaces. They were misled here by the limitations of the microscopical methods available at the time, since it is possible to distinguish quite clearly with modern techniques that even the best polished surfaces consist of systems of intimately overlapping grooves, or 'scratches' (*Figure 1a* and *b*)[4,7,8]. It is in fact

Figure 1. Representative polished surfaces viewed with the optical microscope under phase-contrast illumination: (a) polycrystalline zinc polished by industrial methods (×100). (Courtesy American Electroplaters' Society—Tech. Proc. (1959) 46, 122); (b) single crystal of silver finely polished on magnesium oxide abrasive by metallographic methods (×2000). (Courtesy J. Inst. Metals[6])

apparent when a series of progressively finer abraded and polished surfaces are examined by such methods that the scratches throughout differ essentially only in their absolute dimensions. In this respect, the two types of surface certainly differ only in degree.

One special feature of polished surfaces often noted is the development of appreciable differences in level between the individual grains of a polycrystalline specimen (*Figure 1a*)[4,7,8]. This implies that material is removed from grains sectioned in different orientations at different rates, which can reasonably be expected with a mechanical process of polishing but is scarcely likely with a flowing process. It is also easy to establish that there is progressive and comparatively rapid general removal of material from the surface during polishing[4,8], and this again is natural for a mechanical cutting process. It is not so, however, for the Beilby–Bowden mechanism, which proposes that material is merely redistributed from one point on the surface to another.

Finally, it has been found that a plastically deformed layer is produced on the surface during polishing, the metallographic structure of this layer being very similar to that of the well-known deformed layer produced during abrasion or machining (*cf. Figure 2a* and *b*)[4,7]. It again seems reasonable to conclude from this type of observation that the two processes differ essentially only in degree.

Nevertheless, the difference in degree is a very considerable one, as can be seen from comparing *Figure 2a* with *2b*, and it is reasonable to ask what this difference is due to. It was Rayleigh who first pointed out the fact noted earlier that the result obtained with a given fine abrasive depends largely upon the way in which the particles are supported: an abraded surface is produced when they are firmly attached to a firm backing, but a polished surface is obtained characteristically when they are held loosely on a soft yielding backing. The difference, therefore, is probably a very simple one. The conditions during polishing are such that the abrasive particles can support only a very small load; otherwise they would sink into the backing or roll out of the way. Consequently, they can cut only a very shallow groove.

New Evidence on the Beilby Layer

Even if one accepts that polishing occurs primarily by cutting, it is still possible that a Beilby layer could be formed by a subsidiary process. For example, in most practical polishing operations the surface rubs at some points against the material used to support the abrasive and this might result in some sort of surface smearing; some of the abrasive particles might also rub past or roll over the surface without cutting a chip. The question of the existence of the Beilby layer has therefore to be considered separately from that of the basic mechanism by which polishing occurs.

Figure 2. Metallographic structures of the surface deformed layers produced by industrial abrasion and industrial polishing operations: (left) abraded surface (×250) (above) polished surface (× 2000). The surfaces have been sectioned at an acute angle to give an additional magnification of approximately × 10 in a direction perpendicular to the surface. (Courtesy J. Austral. Inst. Metals[7])

Microscopical Evidence

Of the many experiments that have been carried out employing the optical microscope, one is of outstanding interest. It was first carried out by Beilby himself and can be said to have been the original cornerstone of his theory.

Suppose that a surface is abraded to produce scratches which preferably are arranged in some way that can be easily recognized. These abrasion scratches eventually disappear when the surface is subsequently polished, but it often happens that they seem to reappear when the polished surface is etched. Beilby's explanation for the phenomenon was that the original scratches are merely covered over during polishing by being filled in with the amorphous material. The amorphous material is then dissolved out during etching, so re-exposing the original scratches (see sketches in Figure 3). This is an extremely neat explanation, but it cannot account for many new observations which we have made on the phenomenon[4]. The true explanation is undoubtedly as follows[4]:

A zone of plastically deformed material extends beneath each original abrasion scratch. Material is removed during polishing and the surface is lowered, so that a scratch disappears when the surface has been lowered beneath its root. However, the surface still may not have been lowered beneath the base of the zone of deformed material which was associated with the scratch. Narrow bands of deformed material would then be left in the surface at sites corresponding to those of the original scratches, and it is these which are attacked preferentially during
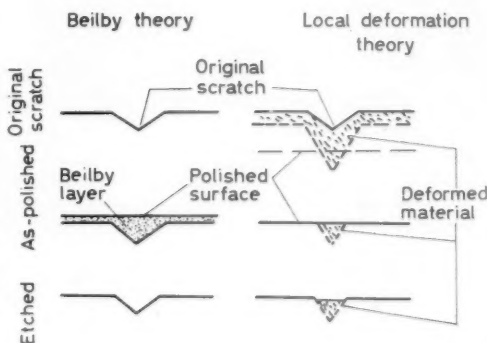

Figure 3. Sketches illustrating the two explanations for the phenomenon of the apparent re-appearance of pre-existing scratches during the etching of polished surfaces. (Courtesy Electroplating and Metal Finishing, (1959), 12, 130)

etching. The features so developed are ' ghosts ' of the original scratches but certainly are not the scratches themselves. This mechanism is also illustrated by a sequence of sketches in *Figure 3*.

Beilby also presented micrographs purporting to show scratches being filled in by flow. This interpretation is at best only one of several possible, and modern evidence indicates that his cannot be correct. Firstly, the most liberal recent estimates of the thickness of the supposed Beilby layer are orders of magnitude less than the depth of the scratches which it is required to fill. Secondly, so much material is removed from the surface during polishing that the pre-existing scratches must rapidly be completely eliminated. Thirdly, BRÜCHE and POPPA[9] have shown directly and convincingly by electron micrography that, at least in the case of glass, it is the asperities that are worn away during polishing and not the depressions that are filled in.

The remaining microscopical evidence which has been advanced from time to time to substantiate the existence of a Beilby layer is similarly found to be untenable when examined critically[4]. Indeed, it is scarcely to be expected that optical microscopy would provide positive evidence on the existence of a layer as thin as the Beilby layer is supposed to be.

Continuity of Overgrowth

It is well known that crystals of a similar, or even a different, sort grown on a crystalline surface may adopt the orientation of the substrate, the phenomenon being known as oriented overgrowth, or sometimes as *epitaxis*. The effect clearly must be related to the regular nature of the unsatisfied binding forces of the atoms exposed at the substrate surface and would be expected to be inhibited by the presence of a thoroughly disorganized layer of atoms on the surface such as the Beilby layer is supposed to be. Here, therefore, is a technique which might be applied to our problem with profit.

We have carried out a suitable series of experiments[5] and found that epitaxed deposits do grow on polished metal surfaces. One of the nicest examples is shown in *Figure 4*. This is a finely polished surface of silver on which sodium chloride crystallites have been grown by the evaporation of an alcoholic solution of the salt. The squares in the field are the small cubic crystallites of sodium chloride and it will be noted that most are aligned with their edges parallel; that is, most have the same orientation, which is that established by the substrate crystal. The micrograph of *Figure 5* illustrates another manifestation of the same effect. A thick electrodeposit of copper has been grown on a polished copper surface, the composite has been sectioned

perpendicular to the original surface and the sectioned surface has been polished and etched. The similarity in the etching colour of adjoining grains in the deposit and substrate indicates that the former have grown with the same orientation as the latter.
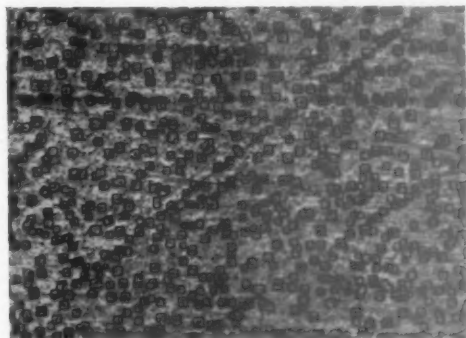

Figure 4. Epitaxed deposit of cubic sodium chloride crystals on a finely polished surface of silver (× 500). (Courtesy J. Inst. Metals[5])
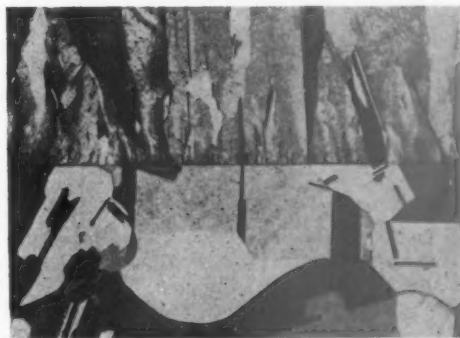
Figure 5. Section showing crystalline continuity in an electrodeposit of copper (top) grown on a finely polished surface of copper. The horizontal line is the trace of the polished surface. (Courtesy J. Inst. Metals[5])

This gross continuity of growth is not necessarily so obvious with more coarsely polished surfaces, and it may even apparently disappear, but it can be shown that this is due merely to misorientation produced in the surface by plastic deformation during polishing[6]. The deposit is still epitaxed with respect to each point at which it was nucleated.

These experiments suggest strongly that there is no Beilby layer on the surfaces concerned but, when

Figure 6. Electron diffraction patterns obtained from polished surfaces of a single crystal of silver; (a) surface polished by industrial methods. (Courtesy J. Austral. Inst. Metals[7]); (b) surface finely polished by metallographic methods using magnesium oxide abrasive. (Courtesy J. Inst. Metals[6])
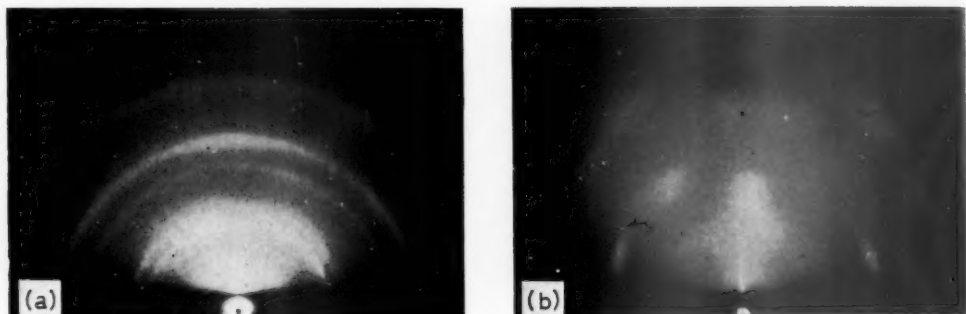
looked at carefully, they are not completely conclusive[5]. There is no need to discuss the details here, except to say that any attempt to reconcile the observations with the Beilby theory does necessitate rather drastic and artificial modifications to the accepted concept of the nature of the Beilby layer.

Electron Diffraction Evidence

The most definitive evidence on the existence of a thin surface layer such as the Beilby layer is supposed to be is to be expected from electron diffraction investigations. Indeed, the Beilby theory was greatly consolidated when polished metal surfaces were first examined by the technique and it was found that they characteristically gave reflection patterns consisting of very diffuse haloes instead of the sharp spots or rings to be expected from a crystalline material[10]. The halo patterns were interpreted as indicating the presence of a liquid-like layer, *i.e.* a Beilby layer, on the surfaces. Although this interpretation has been vigorously disputed by some[11,12], it is probably true to say that the consensus of expert opinion still supported it until recently[13,14].

The real difficulty is that the diffraction patterns obtained are so indefinite that unambiguous interpretation is scarcely to be expected. It has been possible in a recent series of experiments[6,7], however, to obtain a set of quite definite patterns from surfaces of a single crystal of silver polished by both metallographic[6] and industrial methods[7]. The interpretation of these patterns is consequently less speculative.

The diffraction pattern shown in *Figure 6a* is typical of those obtained from comparatively

coarsely polished surfaces. It consists of reasonably sharp diffraction rings which indicate that the surface layers (even those 10 Å or less in thickness) are still crystalline but that the original single crystal has been broken up into fragments which are randomly oriented. This fragmentation is of the sort to be expected from ordinary plastic deformation. The conclusion is reached, therefore, and this is the same conclusion as that reached from the two other independent experimental approaches, that the surface layers of mechanically polished surfaces of metals are crystalline but plastically deformed.

One interesting result is that the extent of the rotational fragmentation indicated by the diffraction pattern and hence, by inference, the degree of plastic deformation in the surface layers, decreases progressively with increasing fineness of polish. A stage is reached with the finest of metallographic polishes where it is very small, and a diffraction pattern clearly recognizable as being the grating pattern of the original single crystal, somewhat distorted, is then obtained (*Figure 6b*).

These definite diffraction patterns are obtained only under conditions where approximately unidirectional scratches are present and where the electron beam is incident perpendicular to these scratches. Under other circumstances, *e.g.* randomly oriented scratches, the rings are much more diffuse in the case of coarse polishes, or may disappear and be replaced by random diffuse scattering in the case of the finest polishes. The latter can be explained by complete internal reflection of the diffracted rays when the surface is very flat[6]. Apparently, a considerable number of asperities must be presented to

the electron beam before sharp diffraction patterns can be obtained in reflection.

Although this new evidence indicates that anything other than very diffuse diffraction patterns is not to have been expected under the experimental conditions used by earlier workers, it does not permit any sound explanation for the halo patterns which they obtained. Many possibilities must be recognized, and speculation on them is probably rather futile at present. It may be noted, however, that much of this earlier work was carried out on surfaces polished by burnishing which, as discussed later, is a very different type of process from that under consideration.

The New Concept of Polishing and of Polished Surfaces

The new view, then, is that a ground or abraded metal surface is polished by the crests of the coarse irregularities present being cut away until they are replaced by a set of much finer ones. Cutting is thought to be the main mechanism involved, but clearly it may not be the only one. Others which come to mind are chemical attack by the medium in which the abrasive is suspended, deformation by abrasive particles which roll or rub across the surface without digging in and cutting a chip, and rubbing by the material used to support the abrasive. The present indications are, however, that factors such as these usually are minor ones in well conducted polishing operations.

In any event, it is fairly certain that the final surface is fully crystalline; in other words, that a Beilby layer is not formed. This is not to say that the surface is not affected in any way. Indeed, we know that it is. The main physical change is that the surface layers are broken up into small but coherent crystalline fragments by a process of plastic deformation, the degree of fragmentation and the depth of the fragmented layer both varying considerably with the method of polishing.

These conclusions were reached from a study of metal surfaces polished by methods using fine abrasives of the type employed in the metallographic laboratory and in the metal finishing industry, and it is to these conditions only that they apply directly. They are probably the polishing conditions of widest interest but there are, nevertheless, others which must be considered.

Perhaps the most important of these methods is burnishing. This is the sort of process where a hard tool or roller, or a cloth or leather not charged with abrasive, is rubbed across the surface, usually under heavy pressure. Cutting clearly cannot be the mechanism involved here. The most obvious suggestion is that the crests of the asperities are smoothed out by being crushed or flattened by the passage of the burnishing tool, but it is unlikely that the process is quite so simple. The circumstances are exactly those of rubbing friction considered by Bowden and Hughes[3] and there is, therefore, very good reason to suspect that the asperities attain high temperatures as the tool rubs past them. It may not be that actual local melting occurs, but at least temperatures of sufficient magnitude to have a considerable influence on the smoothing mechanism could be attained.

In any event, electron diffraction investigations, particularly those carried out by Raether[15] in Germany, leave little doubt that burnished surfaces are extremely severely distorted, very considerably more so than for those polished with abrasives. Indeed, the distortions are so severe that it can be disputed whether it is still reasonable to consider the surface as being crystalline. Ultimately, the matter resolves itself into one of definition, but there may be a case here for retaining something of the Beilby concept. Perhaps cutting and surface flow represent the two extreme boundary conditions under which specularly reflecting surfaces may be produced by mechanical methods. If so, it must be recognized that they are two quite different processes and that conclusions reached about one do not necessarily apply to the other.

References

[1] RAYLEIGH, Lord. *Nature, Lond.* (1901) **63**, 385
[2] BEILBY, Sir George. *Aggregation and Flow of Solids.* London: Macmillan, 1921
[3] BOWDEN, F. P. and HUGHES, T. P. *Proc. Roy. Soc.* (1937) **A160**, 575
[4] SAMUELS, L. E. *J. Inst. Metals.* (1956) **85**, 51
[5] SAMUELS, L. E. *J. Inst. Metals.* (1956) **85**, 177
[6] SAMUELS, L. E. and SANDERS, J. V. *J. Inst. Metals.* (1958) **87**, 129
[7] SAMUELS, L. E. *J. Austral. Inst. Metals.* (1959) **4**, 1
[8] SAMUELS, L. E. *J. Inst. Metals.* (1952) **81**, 471
[9] BRÜCHE, E. and POPA, H. *Trans. Soc. Glass Technology.* (1956) **40**, 513
[10] THOMSON, G. P. *Proc. Roy. Soc.* (1930) **A128**, 649
[11] KIRCHNER, F. *Nature, Lond.* (1932) **129**, 545
[12] GERMER, L. H. *Phys. Rev.* (1936) **49**, 163
[13] FINCH, G. I. and QUARRELL, A. G. *Nature, Lond.* (1936) **137**, 516
[14] THOMSON, G. P. *Structure and Properties of Solid Surfaces.* (Edited by R. GOMER and C. S. SMITH). University of Chicago, 1953
[15] RAETHER, H. *Metaux et Corrosion.* (1947) **22**, 2

C

MODERN TRENDS IN THE PROCESSING OF CANNED VEGETABLES

R. H. THORPE

The Fruit and Vegetable Canning and Quick Freezing Research Association, Chipping Campden

The general principles of processing canned vegetables are reviewed and the types of equipment used for this purpose are described. The modern trend is towards processing in continuous pressure cookers and the impact on the canning industry of the introduction of these machines is assessed with respect to the quality of the products.

I N A N age when the housewife can go into a shop and buy any food she chooses, it is often overlooked that man is still faced with the problem of food preservation. Canning, one of the more recent methods of preservation, has undoubtedly played a major part in giving us the variety of diet which we enjoy all the year round. In fact, the incentives to find new methods are mainly ones of convenience of preparation and not the need to avoid starvation.

Less than 200 years ago, man was still dependent upon the old established methods of preservation such as drying, brining, salting, jam making, pickling, curing and chilling. While useful, these methods could hardly be said to have given people more than subsistence level, especially in the late winter and early spring.

On storage, any food in its natural state will decompose, the decomposition being due mainly to the presence and normal activities of micro-organisms —bacteria, yeasts and moulds. The older methods of preservation have one common factor—inhibition, the physical or chemical state of the food being altered in such a way as to render it unsuitable for the growth of micro-organisms. No express effort is made to kill micro-organisms already in the food and only limited precautions need be taken to prevent subsequent infection.

In bottling and canning there is an entirely different principle in which inhibition plays no part or, at least, is not wholly relied on. This principle is comparatively new, but even so it was discovered and developed very successfully, like the older methods, before the cause of spoilage in foods was understood. Canned food is left in a state highly susceptible to spoilage but, because there are no living micro-organisms in it and no chance of re-infection, spoilage does not occur.

These ends are attained by enclosing suitably prepared food in a container that can be sealed hermetically and then sterilizing the food by means of heat to kill all micro-organisms capable of growing under the conditions that prevail in the container.

This procedure was first clearly stated, with the exception of the reference to micro-organisms, by Nicholas Appert in 1810 after experiments extending over fifteen years. In the same year Peter Durand took out a patent for the use of tin-plate containers for the preservation of food.

Although this year marks the 150th anniversary of the use of tin-plate containers it is in the last forty years, with the application of the sciences of bacteriology, chemistry and physics together with engineering skill in designing equipment, that we have seen the main development and growth of the industry. Since 1945 three main trends have predominated— the improvement of quality, the speeding up of canning lines and the replacement of the batch system of processing vegetables by a continuous one.

Within the industry the term ' processing ' is applied only to the heating of closed cans to obtain stability of the food. The major, closely interrelated, factors which have to be considered are— stabilization of the product, quality, uniformity and economy. While stabilization of the product is the primary aim, it must not be attained at the expense of the others. For example for cans of peas a process at 212°F equivalent to 23 min at 240°F would take about ten hours. Either process would be equally satisfactory when considering sterilization, but obviously the latter would be highly uneconomical besides greatly overcooking the peas.

The process or degree of heating is defined by two variables—the temperature applied to the can and the time that temperature is sustained. However when evaluating a process the initial temperature of the can contents and the rate of heat penetration into the can must also be considered. The latter depends upon the size and shape of the can, the nature of the contents and the degree of agitation, if any, applied to the can during the process. Whether a process of given value is effective or not depends on the degree of initial infection, the heat resistance of the micro-organisms and the acidity of the product.

Heat Resistance of Micro-organisms

The micro-organisms—bacteria, yeasts and moulds —that may cause spoilage of canned foods are all minute forms of plant life. In their active or vegetative state micro-organisms are rapidly killed at temperatures of the order of 170°F. However the spores formed by certain bacteria are much more resistant to heat and many can be killed in a reasonable time only at temperatures considerably higher than 212°F.

When bacterial spores are subjected to moist heat they have a logarithmic order of death and their heat resistance is generally measured in terms of the decimal reduction time for a given set of conditions, *i.e.* the time required to reduce the number of viable spores to one-tenth of the number viable at the beginning of that time.

Acidity of the Product

The pH of a product determines to a great extent the process necessary to stabilize it. For the purpose of processing, canned foods may be classified as either acid (below pH 4·5) or low acid (above pH 4·5).

Most spore forming bacteria, including the food poisoning organism *Clostridium botulinum*, will not grow in foods with a pH below 4·5. Acid foods, such as tomato products and fruits can be processed at 212°F, while with the low acid foods, comprising all vegetables and also meat, fish and milk, stability can only be obtained by killing all bacterial spores. Low acid foods must be processed for at least the minimum times accepted as being necessary to make the foods safe against botulism. In practice this necessitates the use of temperatures higher than that of boiling water. The safety factor (far greater than for most of the hazards likely to be encountered in modern living) has been proved in practice; no case of botulism from canned foods produced in British or American canneries has been reported since these safeguards were introduced over thirty years ago.

Rate of Heat Penetration

The rate at which heat penetrates to the coolest part in the can is important in determining the value of a process. When the contents of a can are solid or sufficiently viscous to prevent any convection, heat passes through the contents from the external surface of the can by pure conduction, the contents obeying the laws of heat conduction in solid bodies. Most pure conduction packs behave very much alike, and the rates of heat penetration depend only on the dimensions of the can. Assuming an even distribution of initial temperature, the point of greatest

temperature lag at any time during the process is at the geometric centre. The centre of the can receives the least process value while the outermost layers may be considerably overcooked.

For convection packs, where the can contains a liquid of low viscosity, or such a liquid together with solid bodies, heat penetration is much more rapid than for a conduction pack in the same size of can. This may clearly be seen in *Figure 1*.

A conduction pack, such as beans in tomato sauce or thick soup, where the contents are fairly mobile, particularly at elevated temperatures, may be made into a convection pack by agitation or rotation of the can so that 'forced convection' is obtained and advantage may be taken of this to reduce process time unless agitation is detrimental to the quality of the pack.

Cooking

It must be realized that processes which are equivalent with respect to sterilization are not necessarily equivalent with respect to cooking. The temperature coefficient for the rate of cooking is generally smaller than that for the rate of killing bacterial spores. A factor of 2 for each 10°F change in temperature may be taken for cooking while the
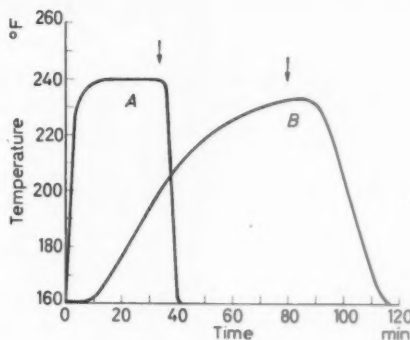

Figure 1. Heat penetration curves for the centre of A2 cans processed at 240°F, with an initial temperature in the cans 160°F. Curve A is for garden peas in brine (convection pack) and curve B for beans in thick tomato sauce (conduction pack). The arrows denote the beginning of cooling

factor for the death rate of spores is about 3·6 for each 10°F change. For packs heating by convection or forced convection, the higher the temperature of processing the less the cooking effect for equal sterilization and conversely the greater the degree of sterilization for equal cooking.
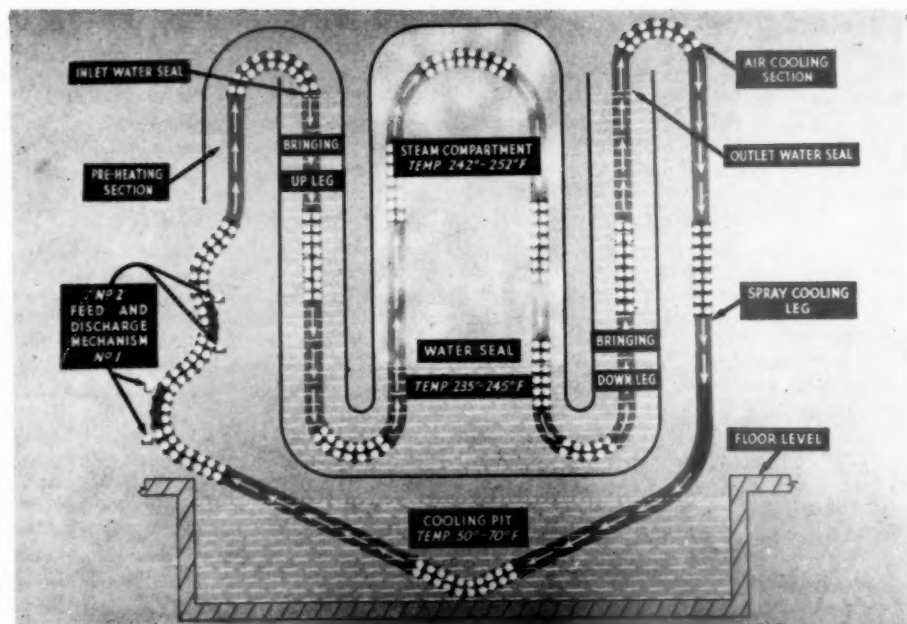
C*

*Figure 2. A diagrammatic representation of a Mitchell-Webster hydrostatic pressure cooker.
(Courtesy Mitchell Engineering Ltd.)*

Processing

The basic operations in conventional canning procedure are preparation of the food, filling of the cans, sealing of the cans, processing and cooling. Developments in cannery practice and equipment for all these operations have been extensive, but discussion will be confined to processing.

Saturated steam is a very suitable medium for processing. It condenses on the cans and has a high latent heat of vaporization, and it is convenient and cheap as the condensate need not be recovered. Although the use of pressure vessels is necessary to attain the temperatures required for processing low acid packs, the pressure of the steam compensates for most of the internal pressure in the can. Provided the cans have been properly filled and closed at a suitably high temperature the excess internal pressure—or strain pressure—will not be sufficient to harm cans even of the largest diameter.

Equipment for processing in hot air at atmospheric pressure has been developed in Sweden and France. These machines are successful, but for low acid products cans of the smaller diameters only may be processed; cans of larger diameter may become distorted owing to excessive strain pressure.

In this country the only medium used at present for processing canned vegetables is steam under pressure. Before the introduction of continuous pressure cookers all processing of vegetables was carried out in vertical or horizontal retorts.

Retorts

There is considerable variation in the value of nominally identical processes in retorts, both from can to can in one retort load and between loads. Among the causes of these differences are variation in initial temperature in the cans due to some cans standing longer in crates than others, and, unless venting is very efficient, variation in the processing temperature within the retort; inefficient venting allows a pocket of residual air to remain at the centre of the retort and here the temperature may be much below the processing temperature for a large part of the process. The usual method of cooling, by flooding up from the bottom of the retort, may also contribute to this unevenness, especially to the degree of cooking, because during cooling the cooking effect falls off much more slowly than the sterilizing effect. The use of top sprays reduces this differential cooling but may cause ebullition in the cans due to the reduction of pressure in the head

spaces, and in some packs this ebullition can cause considerable breakdown of the contents.

If the steam pressure is reduced too rapidly by blowing down or condensation while the cans are hot, the strain pressure is greatly increased and distortion of the cans, especially those of larger diameter, is likely to occur. This is overcome by pressure cooling, the external pressure being maintained by means of compressed air at least until all the cans have been covered with cooling water.

With smaller diameter cans, retorting capacity can be considerably increased by blowing down the retort at the end of the process and cooling the cans in a canal. This has the added advantage of economizing in cooling water.

Most canneries using continuous cookers still maintain a certain number of static retorts as a precaution against mechanical failure and at the height of the vegetable season, particularly of garden peas, these retorts are brought into use to relieve the load on the continuous equipment.

Continuous Cookers

By improvements and new designs the capacity and speed of continuous cookers have been steadily increasing and this has allowed a general speeding up throughout canning lines, resulting in greater production without the necessity of installing more lines. This general speeding up has been successfully paralleled in the design of filling and closing machines. Today a fast pea canning line operates at two hundred cans a minute; a non-agitating valve type cooker will take the cans from one such line and the more recently introduced hydrostatic cookers will each take two fast lines.

Non-agitating valve-type cookers are chambers in which the required steam pressure may be maintained and into which the cans are introduced singly and continuously by means of a valve. Conveyed upright on a chain, the cans traverse the steam chamber and then pass by means of a transfer valve into a smaller pressurized cooling chamber where sprays partially cool the cans to decrease the strain pressure. Final cooling is carried out at atmospheric pressure.

In rotary valve-type pressure cookers the cans are conveyed by reel and spiral systems through cylindrical processing, pressure cooling and atmospheric cooling chambers. The cans roll on the outer casing for about one-third of each revolution of the reel so providing intermittent agitation. Many convection packs can be processed satisfactorily in this type of cooker but their main advantage over non-agitating cookers is in their use for those conduction packs that show greatly increased rates of heat penetration when cans are agitated.

Figure 3. A Carvallo hydrostatic pressure cooker during installation. (Courtesy Mather & Platt Ltd.)

Compared with retorts valve-type cookers give savings in space, steam and labour for a given output and have the advantage that every can receives the same cook. Besides these, the absence of come-up times and in the rotary cookers the increased rate of heat penetration due to the agitation, allow higher processing temperatures and shorter times to be used than are practicable with retorts. On the debit side, the canner must consider capital costs, limitation of each machine to one or two can sizes, more complex maintenance and the liability to stoppage due to jams in the valves or mechanical failure. With improved design jams have been less frequent and the times of stoppages due to those that occur has been shortened by provision for their rapid release.

Hydrostatic Pressure Cookers

The recent introduction of hydrostatic pressure cookers for processing canned vegetables has meant the elimination of mechanical valves and a great increase in processing capacity. The steam pressure

in the processing chamber is sustained by tall columns of water, one at the entrance and the other at the exit. Cans do not pass directly into the steam chamber through a valve but are carried on horizontal carrier bars, or in perforated cylinders, attached at each end to travelling chains, up to the top of the machine, down through the water of the inlet column, through the steam chamber in one or more loops, up the exit column and finally down under cooling sprays (*Figures 2* and *3*).

The temperature of the water in each column has a gradient from about 180°F at the top to a temperature at the seal some 5° or 10° below that of the steam. This difference is necessary to avoid the risk of boiling in the columns. Forced cross circulation maintains smooth temperature gradients in the columns and gives economy in steam. This matching of the external conditions to the changes in temperature and pressure in the cans, especially during cooling, is an important advantage of this type of cooker because the chance of damage to the contents through ebullition, or steam evolution within the tissues, is greatly reduced. Further advantages are slow rate of movement of the chains, greater capacity and the small floor area required, but the last of these is offset to some extent by the great height of the cooker. The long time of travel in the columns also tends to reduce benefits obtained from high-temperature short-time processing.

Future Trends

Of the trends in modern canning practices, the increasing speeds of canning lines and the change over to completely mechanized vegetable lines are now well established. The third trend, that of improvement in quality, has already been briefly mentioned. The quality of a pack depends on many variables from the variety grown to the way the raw material is handled and prepared during the pre-process operations. There have been steady improvements in the past years but in the actual processing it is only recently that the advantages with respect to quality, offered by high-temperature short-time processes, have been implemented.

For convection and forced convection packs a process at 250°F, say, that is equivalent in sterilizing power to a given process at 240°F, will cook the contents to a lesser degree. If the processing temperature were 260°F, then the reduction in cooking would

be even more noticeable. In theory it would be possible if desired, to carry on increasing the processing temperature even higher than 260°F. However with conventional processing there are certain practical limitations. For retort processing, temperatures higher than 250°F give no worthwhile saving in time. With valve-type continuous cookers the limiting temperature is 260°F or a few degrees higher. No worthwhile time would be saved by going to 270°F even if it were possible, and most cans would not withstand the initial pressure shock. In hydrostatic pressure cookers the maximum temperature depends on the height of the water columns, 56 feet being required for a temperature of 260°F. Little advantage is gained by using higher columns and processing temperatures greater than 260°F. Although the canner, using conventional processing methods, is limited to a temperature of 260°F he still has the choice of two approaches. If he is satisfied in respect of quality with a process say at 240°F he may process at 250°F or 260°F and so obtain a higher degree of sterility for the same quality. Alternatively if he considers that a process at 240°F overcooks the product, he may improve it without increasing the chances of spoilage by processing at a higher temperature or he may of course realize a proportion of both aspects.

If the advantages of temperatures higher than 260°F are to be utilized then the time lost in heat penetration must be reduced and this means in effect that conventional canning practices cannot be used and the product must be sterilized before it is in the can. This can be done by pumping the material through a heat exchanger. There must be a heating period (generally a few seconds) and a holding period immediately followed by cooling. The cool, sterile product is then filled into sterile cans which are closed with sterile lids under conditions that preclude reinfection. This procedure is known as *aseptic canning* and has so far only been applied to a limited extent in America to homogeneous products such as soups, purées and milk products.

Theoretically there is no reason why heat exchanger systems cannot be designed for a much wider range of products and a major part of the industry would then be in a position to discard the traditional practices initiated a century and a half ago by Nicholas Appert.

ELECTRICITY SUPPLY IN GREAT BRITAIN
and some associated questions

ARTHUR PALMER

Electrical Power Engineers Association

This essay discusses the organization of the nationalized electricity supply industry in Great Britain in relation to the several post war Acts of Parliament. Achievements and problems of both the generation and distribution sides of the industry are described with nuclear power development and the prospects for a national fuel policy as a background. Finally, the author suggests four possible fields of investigation for the strengthened research team of the industry.

PUBLIC electricity supply in practically all modern industrial countries is regarded as a public utility which means it is subject to a close degree of public and legislative control. In most countries also, ownership is mixed being partly public and partly dependent on private investment. In some countries, including Great Britain, electricity supply is nationalized.

Organization

The Act of Parliament which nationalized all electricity undertakings became law in 1948. Since then there have been two further Electricity Acts, each modifying in organization though not in principle the primary nationalization act. The Electricity Act (Scotland) 1954 separated Scottish electricity organization—probably more for political than substantial technical reasons—from that south of the border. The 1957 Act based, in part at any rate, on the recommendations of the Herbert Committee of Inquiry gave virtual financial autonomy to the twelve English and Welsh area or distribution boards and made the ' wholesale ', generation and bulk transmission side an independent concern under the direction of the Central Electricity Generating Board. Broad co-ordination is now accomplished by the Electricity Council, a confederal body consisting of the chairmen of the area boards and the generating board, fortified by a few ' independents ' but with advisory functions and not executive powers.

One can summarize the system by saying that public electricity supply is the responsibility of thirteen public corporations in England and Wales, one wholesale and twelve retail; and of two public corporations in Scotland, the South of Scotland Electricity Board and the North of Scotland Hydro-Electric Board, each autonomous and embracing in this case both generation and distribution. Before nationalization, of course, there were some hundreds of undertakings in the country.

The outstanding advantage which nationalization has brought about is the opportunity given for rationalization of what is essentially a planner's industry. Large operating and technical savings have been made already and the only ground for argument is whether these savings are not somewhat smaller than they should be due to possible administrative waste brought about by arbitrarily imposed organization. But the history of electricity supply in a country so devoted to constitutional and parliamentary checks as Britain has always been a struggle of technical developments to break out of an inadequate or too confining legislative framework. In many ways the struggle is inescapable because electricity supply must involve vast capital expenditure, the breaking up of public roads, the compulsory acquisition of land of considerable amenity value, the crossing of private property by overhead lines—in short, an expert's territorial monopoly, which the citizen and his representatives watch with jealous and cautious eye.

There are no absolute forms of ideal industrial organization and utilities present special problems in being halfway between state services and normal productive industry; the 1947 Act, with the near dictatorship of the Central Electricity Authority, went too far towards centralization, the 1957 Act has probably swung the pendulum too hard in the other direction. The boards and in particular the C.E.G.B., may conclude they could well do their work more comfortably without Electricity Council officials breathing down their necks. Similarly the independent members of the Council may feel that they are prisoners of the boards and in their secret hearts long for those reserved central powers which Sir Edwin Herbert's committee[*] recommended in vain for the reorganized industry.

[*] In 1954 Sir Edwin Herbert was appointed chairman of an independent committee by the Minister of Fuel and Power: 'To inquire into the organization and efficiency of the electricity supply industry in England and Wales in the light of its working under the Electricity Act 1947 and to make recommendations.' The committee reported in 1956.

Electricity Generation

Electricity supply is a secondary fuel industry; it takes primary energy sources such as the combustion of coal, the flow of water, or nuclear fission and converts these into a universal energy medium which is extraordinarily clean, adaptable and convenient but not without a degree of danger in use. The industrial legislative programme of the Parliament of 1945–50 embraced the concept of bringing into national ownership so-called ' basic industries ' in order to provide ministerial control over the economy as a whole. Yet already in the short space of a decade it is evident that there is nothing very basic about, say, either coal or railways. Each has become something of a national problem, largely because new technical developments and discoveries are providing other ways of performing roughly the same services at comparable costs. However, it is not easy to visualize any kind of modern society without electrical energy available at its service in massive quantities. Electricity being a fundamental requirement of twentieth century civilization, the output of the industry is governed to a very great extent by almost automatic external factors. Consumer preference, publicity and price can modify or increase demand but experience shows that modern

Figure 1. Output of electricity per head of population. The straight line shows the doubling of units per head of population every ten years

communities in fact tend to double their consumption of electricity every ten years this representing an average advance of 5–7 per cent per annum (*Figure 1*). Electricity consumption is a direct

reflection of productivity, personal incomes and the national standard of life in general.

The total production for the year 1958–59 of electricity in the stations of the Central Electricity Generating Board was 86,733 million units. The maximum demand on the C.E.G.B. system was 20,899,000 kilowatts which occurred on the morning of 14th January, 1959 at about 11.0 a.m. This British power production originated in a variety of plants overwhelmingly for the present coal fired, but supplemented by a little oil firing in the South of England and water power in Scotland. Fairly soon the general picture will be modified by modest supplies of nuclear fission energy (*Figure 2*).

The policy of the Central Electricity Generating Board is to concentrate production in far fewer but increasingly more efficient stations. While total output capacity has increased over the last ten years by one and a half times the number of separate stations has fallen from 291 to 238. In these larger power stations the individual generating sets provide, with their assorted boiler units, up to nine times the output of the standard 60,000 kilowatt set of 1948. Future programmes include power units of 500,000 kilowatt and others of 275,000 and 200,000 kilowatts. The advantage of these giant sets, with their high steam pressures and temperatures, are that they generate more electricity per ton of coal and economize in materials and building space. In 1920 one ton of coal produced 640 kilowatt hours of electricity; in 1948 1,506 kilowatt hours; and at present the figure stands at 1,790 kilowatt hours for each ton of coal. While older stations use 15 cubic feet of space for each kilowatt of installed capacity, the latest stations are down to 8 cubic feet per kilowatt. Altogether, these economies have resulted in capital costs for power station construction remaining at £50 per kilowatt; this is the same figure as in 1948, despite an increase of approximately 70 per cent in the price of materials and labour.

The average figure of £50 per kilowatt given above for ' conventional ' coal fired or oil fired power stations in capital construction cost should be compared with the £145 per kilowatt which is generally reckoned to be the price at which the first of the nuclear power stations will be completed. It is for this reason and others that the future role of atomic power in Britain now seems likely to be a great deal smaller than was expected only a few short years ago. With increased interest rates the cost of building nuclear power stations has in fact reached such a figure that it is doubtful if the programme is immediately justified at all, except on the assumption of the need to keep up with the American Joes
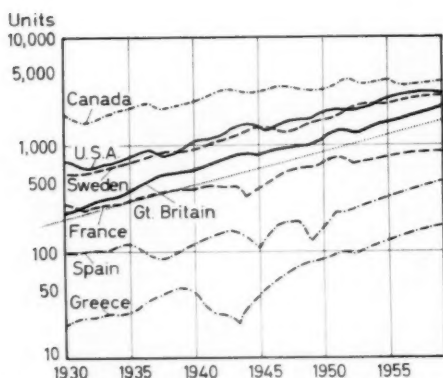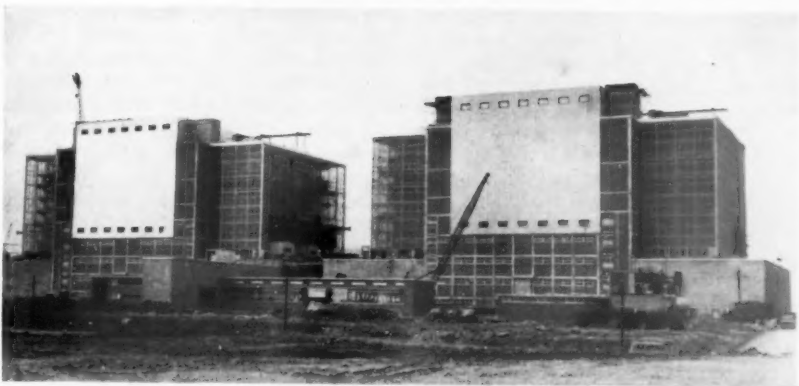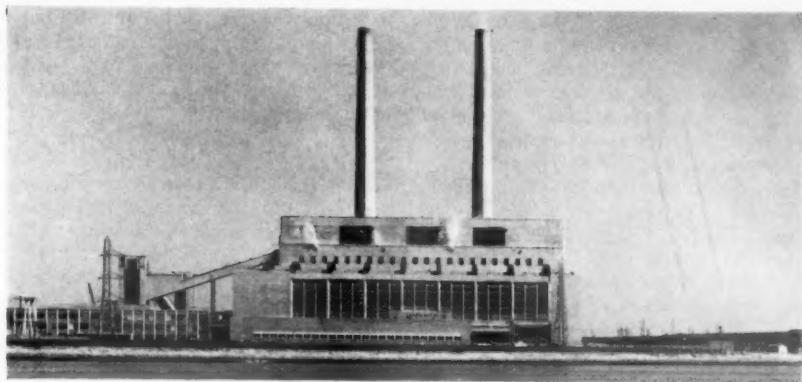
Figure 2. The three types of power station.
Top: Coal fired station (Blyth A, North Eastern Division)
Centre: Oil fired station (Artist's impression of Bankside)
Bottom: Bradwell nuclear power station

and the Russian Ivans or as a rather elaborate research project. The hope of bringing down the capital cost of nuclear power stations depends on technical innovations in reactor design and this in turn depends on using big reactors. A feature of the operation of nuclear power stations is that they cannot be started up and shut down as readily as conventional stations and must be used, therefore, to supply the basic continuous twenty-four-hour electricity demand. Even with a completely interconnected system, there are limits to the extent of this continuous demand and a small number of very large nuclear power stations could absorb it all compelling the Generating Board to forego the use of cheap up to date conventional power station. Although nuclear power station costs fall in proportion to increase of size so do conventional station costs and for the present the latter are falling more rapidly.

Looking back at the history of the British nuclear power programme from the original 1955 White Paper through the ' expansion ' period of 1957 to the present enforced contraction phase one cannot help suspecting that those who wished to make haste slowly with nuclear power have been largely justified by events. For a time the glamour of the new miraculous power source and the prestige of the brilliant men responsible for its development took all by storm in the public mind and at Whitehall. But the fact remains that nuclear power for the immediate future using the plants now in construction is not going to usher in an era of cheap electricity; it is likely to make electricity slightly more expensive to the consumer than it would have been otherwise. Hope of this situation changing must depend on technical innovation as already stated, and reductions in the world price of nuclear fuels which could allow nuclear stations to offset high capital costs by operating more cheaply. According to the latest estimates the break-even date is 1970 when both types of power plant will be turning out units at 0·55d.

Looking ahead, the greater part of electric power production in Great Britain for the next few decades is likely to be in high efficiency, coal or oil fired power stations located at those places where low fuel costs and adequate cooling water supplies keep the cost of production down to the minimum. In making a choice between coal and oil firing, it is important that the Generating Board should be allowed reasonable flexibility. The relative price situation can easily change from year to year with an alteration in the world oil supply position or by substantially improving the coal output per man year. Absolute dependence on any one source of fuel supply is best avoided and this is a consideration separate from ministerial pressures to use at one time as much oil as possible and then later on as little as possible because of passing difficulties and political expediency.

National Fuel Policy

At this point it is probably appropriate to discuss the feasibility of a national fuel policy. This is interpreted sometimes as giving an absolute preference to coal everywhere as a primary energy source which is a little too simple from the electrical point of view. Transport costs enters into total fuel costs as do production costs and hence true cost must be stated in terms of point of use on a national scale. For instance as transport costs of coal have risen with countrywide planning it has become increasingly sensible to build power stations in coal producing areas and take the electricity via the grid to the areas of maximum demand in contrast to prewar practice which scattered power stations along the Thames and provided fleets of colliers to bring coal by sea to them. However, at the time that practice was roughly sound economics and in any case municipal electricity committees and company boards of directors could hardly be expected to escape from thinking in local terms; things had to pay of course but always on an assumed normality which was never challenged.

This is of interest today because those who ask for a fuel policy should not mean simply that the financial troubles of the National Coal Board be lessened by transferring uneconomic working to the electricity industry; or that the Ministry of Power, in pretending that its policy is a masterly commercial strategy based on letting true costs assert themselves, should ignore the inconvenient fact that much oil burning and the nuclear station programme are imposed decisions that could never have come into currency had true cost really been the determining factor. Actually there is no organization in existence at present which can fairly apportion fuel usage in accordance with objective merit and as long as the N.C.B., C.E.G.B., the gas boards or the oil combines try to do the impossible then the results are bound to be unsatisfactory for it is as much against nature for the boards and the combines to emancipate themselves from their own private worlds as it was for the pre-war undertakings in their own day.

If a need for national fuel policy is regarded as of sufficient urgency to warrant a major disturbance then it could possibly be obtained by creating a National Energy Commission to control primary energy sources (coal mines, oil imports, water

Figure 3. Schematic diagram of the supergrid as it is
planned up to 1963 showing the Grid Control Areas
(G.C.A.s)

supplies, uranium processing plants) and licence conversion agencies (conventional, nuclear and hydro power stations, gas works, coke plants, oil refineries). The N.E.C. would then direct supplies of secondary energy and fuel to distributing organizations (electricity boards, gas boards, solid fuel and oil retailers) at true cost according to the estimated consumer demand calculated at reasonable intervals. This proposal is admittedly a little utopian but in the long run surely the concept of energy available in various forms must take the place of competing fuels and be given national commercial expression?

The Grid

The Generating Board's transmission system—generally known as the Grid—is the largest of its kind under a single control in the world. It consists of nearly four-hundred switching stations and about six thousand miles of high voltage transmission lines; for the most part it operates at 132,000 volts but already superimposed upon this earlier primary

system is the super-grid working at 275,000 volts, and eventually parts of the system will advance to 380,000 volts. The higher voltages allow larger quantities of electric power to be transmitted at lower total cost as well as reducing the total number of lines required and avoiding some of the delays and difficulties inevitable when a great number of way-leaves to cross private property and statutory consents from the ministries are required.

The grid system operates as a whole; stations feed into the interconnected lines at the most sensible points in relation to efficiency and economy generally and supplies are taken off as required although power flow in certain directions can be hindered by the inadequacy of individual lines. In order to operate the interconnected system with maximum effectiveness it is necessary that day to day studies be made of load requirements on a territorial basis in relation to the characteristics of particular power stations and the working efficiency of the plant available in them. For this day to day control there are seven operational areas in England

and Wales, each with a control centre (*Figure 3*); the work of the area controls is supervized by a national control in London.   By agreement the South of Scotland is under the same arrangements for daily operation as the rest of the kingdom; the South of Scotland system in turn is interconnected with the transmission network of the North of Scotland Hydro-Electric Board.   The bounds of interconnection will be extended when cables carrying direct current (which gives flexibility of operation) link the electricity systems of the United Kingdom and France, it is hoped within two or three years from now.

Load Factor

In a densely populated, heavily electrically loaded country such as Great Britain the interconnection of power supplies has advantages over any other possible method for the production of electricity is at every hour of the day throughout the year concentrated to the greatest practicable extent in plant having the lowest fuel cost per unit sent out.   Also security of supply is more or less guaranteed; the failure of any unit in the system, whether it be a power producer or a power transmitter, makes little difference in relation to the great number still remaining in service.   Since electricity cannot be stored on any really practical scale it must be used

at the moment it is made and the interconnection of all supply sources keeps the extra plant necessary to meet load fluctuation down to a minimum. Without interconnection each separate system would have to provide its own reserve plant and lines to meet the local maximum demand even if this lasted only for an hour or less on one winter's day in December or January (*Figure 4*).

The sentences just written stress the importance of 'load factor'; this expression has a well known bearing on economical power production.   Load factor can be defined as the ratio of actual units produced or sold during the year to the units which would have been produced or sold had the maximum demand on the undertaking been maintained day and night throughout the year.   As the capital investment of the undertaking is determined by the maximum demand, to improve the load factor means to sell more units for each £1 or £1 million of invested capital.   For the year 1958–59 the load factor of the British electricity system was a little over 47 per cent; in 1920 it was barely 25 per cent.

Some critics argue that this improvement is nothing like good enough and that it compares unfavourably with figures obtained, for instance, in the United States of America.   Certainly it should be the business of electricity suppliers to offer
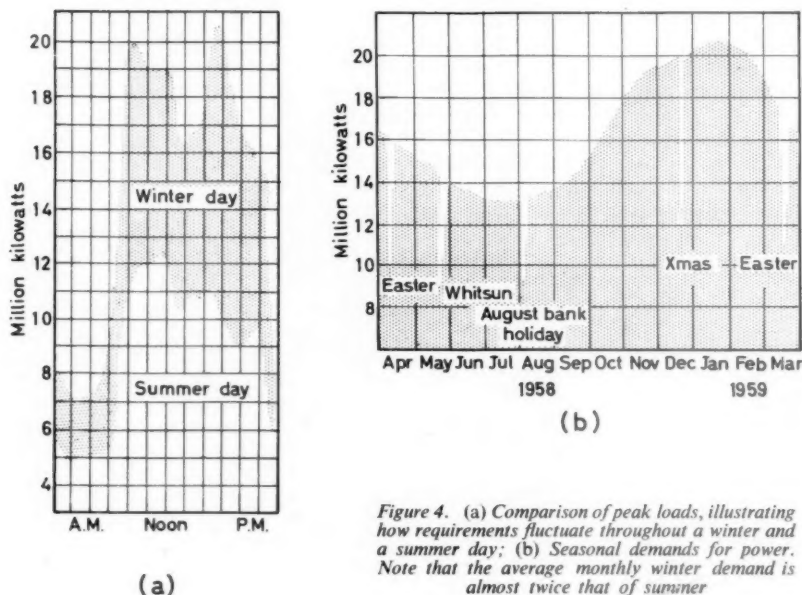

(a)

(b)

Figure 4.   (a) *Comparison of peak loads, illustrating how requirements fluctuate throughout a winter and a summer day;* (b) *Seasonal demands for power. Note that the average monthly winter demand is almost twice that of summer*

attractive ' off peak ' prices for electricity in order to induce consumers to use power around the clock. This the area distribution boards claim they are doing. By scientifically designed tariffs they say consumers are encouraged to develop winter night or summer use and reduce winter day load. But because the total consumption of electricity is a reflection of national activity in fairness it must be accepted that the load factor of an electricity system is to an extent outside the control of the supplier; it depends enormously on population habits. If a law were passed, or if agreements could be reached between employers and trade unions to the same end, for production in factories to be organized on a universal shift system, not only would there be vast economies in the use of industrial capital but the saving would be reflected back to the advantage of the electric power system.

Distribution

As already explained a distinctive feature of most of British electricity supply is the separation of generation from distribution. Not only does the separation possess objective technical merits but the starting point can be seen historically in the Electricity Acts of 1919 and 1926 and it was natural enough that the nationalizing measure of 1947 should accept a trend already established. Nevertheless technical logic and historical inevitability have not entirely left area board opinion content with the prohibition on making their own product and Sir Edwin Herbert's committee was even asked to recommend the ending of the generation–distribution divorce and reconciliation of the parties. The Herbert Committee rejected the separatist plea but conceded that the centralized organization of the wholesale process could be justified only provided area boards were supplied more cheaply than they could make electricity for themselves. The subsequent 1957 Electricity Act reflected this view by restoring limited generation powers to distribution authorities, but curiously enough the same act placed control of the bulk supply tariff for area board supplies with the Generating Board.

Although there could probably be thirty as easily as fourteen area boards in England and Wales for distribution, the actual division is supposed to be based on objective consideration of geographical and technical factors. It was thought for instance to be desirable that board boundaries should run through sparsely populated districts and that each board should contain as far as possible a fair balance of rural and urban loads. The difficulty of achieving this ideal can be understood by comparing say Greater London with the South West of England. London not only embraces about one

quarter of the total population of the country but absorbs a large part of the total national electricity consumption. With the exception of Bristol and Plymouth the south west, on the other hand, is almost entirely rural. It is only to be expected, therefore, that the economics of distribution will vary vastly between the two areas. The south west was driven at one time into the financial red because of the heavy burden of rural electrification costs. London can proudly boast that it has connected all its farms. However these are the extreme cases; the country dweller has achieved perhaps more than any other single section of the community from the electrical developments of the last decade without any undue burden on the urban consumer. About eighty per cent of total farms now have electricity which works out at about 1,100 farms connected per year, or over twice the pre-war rate of connection.

Although the spotlight of publicity tends to concentrate on rural electrification, area board management has had to give equal thought to the reinforcement of distribution systems as a whole to make them capable of bearing the heavier electricity loads which intensified industrial and domestic development has called into existence. The inability of an electricity undertaking to supply an electrical demand is always regarded by the public as a cardinal sin. If for instance, a factory owner decides for reasons convenient to him to place his new works in a particular place then he will not complain overmuch if later he finds that some raw material needed in the process has to be brought a great distance at a high price or that skilled labour is scarce. He will put the blame either on the nature of things or even acknowledge his own lack of foresight. Should, however, the area board tell him that the quantity of electricity which he requires is unexpected and unprecedented and that he will have to wait until the mains are reinforced before he starts production, then there is likely to be a tremendous row and protests all round ending up maybe with a letter to the Member of Parliament. Being, therefore, aware of what is expected of them electricity suppliers try to anticipate demands continually even though this must from time to time mean unproductive investment.

The rationalization which has gone with nationalization recently has allowed boards to plan their areas comprehensively and make economies untrammelled by parochial boundaries; systems are loaded more evenly and hence more efficiently. In co-operation with the Generating Board points of supply for the distribution systems have been arranged realistically thus avoiding unnecessary

D

extensions and duplication of lower voltage feeders. Low voltage and excessive voltage fluctuation are weaknesses which are always difficult to overtake when loads are continually advancing and the problem is aggravated by reported troubles in obtaining sites for substations in built-up areas. With the almost universal use of television sets the citizen is very much aware of deficiencies in the system voltage but does not always co-operate in provision of the technical remedy in the form of more supply points. But in general the standard of operating efficiency on supply systems has improved so remarkably that few consumers today remember the uncertainty of electricity in early times. (This of course is to except the immediate post war era of ' load shedding ' due to war time neglect.) The improvement in continuity and reliability has been brought about not only by the rationalization just mentioned but by a steady advance in the design and performance of equipment, protective systems and, in rural areas, better techniques for dealing with lightening troubles. Up-to-date communication methods such as mobile radio have also facilitated speedy attention by staff to breakdowns.

Research

The article opened by pointing out the special nature of the industry as a public utility half way between government service as such and ordinary productive industry. For that reason it lives more in a political atmosphere than most commercial enterprises would welcome and at the same time the industry lacks the clear ministerial responsibility which shelters the civil service. Hence the boards can often see openings and needs which their business instincts tell them should be followed or satisfied but they are inclined to wonder if the ' public interest ', or the imagined current interpretation of that interest, permits action. There are a number of examples of this split-mind state of affairs which are not the concern of this essay but it also led quaintly enough at one time to the partial neglect of research. Here the feeling was that the makers of plant were the main people to act aided by appropriate research organizations and for the nationalized industry to do a great deal would be to trespass in the reserved fields of others. Fortunately the Herbert Committee did much to dispel confusion by pointing out that before nationalization it was understandable that the various small undertakings could not finance research on any significant scale, but nationalization had created a new situation of which full advantage should be taken. The boards would not then be so dependent on electrical manufacturers for technical progress and innovations. In any case a wider appreciation of the part science could play in forward planning would be an immense advantage to the future health of the industry. This small lecture was taken well to heart and now a very large expert scientific team is being built up particularly by the Generating Board. Within a few years electricity supply should be in the forefront of those British industries applying research to the solution of its problems on an extensive scale. What then are the problems which need investigation?

It is beyond both the scope of the writer and his knowledge to set out in any kind of detail a research programme for the industry but as a close observer he suggests research must divide itself fairly naturally according to the headings below:

(*1*) Investigations into fundamental questions of electricity production and use: for instance ways and means of escaping from the limitations of the thermodynamic cycle and methods of solving the too long outstanding energy storage problem.

(*2*) Investigations into reductions of cost in all the fields of generation, transmission, distribution and utilization: this is primarily a scientific and engineering matter but it must occasionally take account of psychology or even sociology.

(*3*) Investigations into techniques for reducing the social nuisance of electrical processes: in a once beautiful island packed with more and more human beings demanding simultaneously the often mutually contradictory ends of higher *and* better standards this is no easy task.

(*4*) Investigations into the future possibility of maintaining human interest in an industrial environment which when ideally organized and arranged will simply record the almost effortless glide of electrons from genesis to consummation!

The illustrations are reproduced by courtesy of the Central Electricity Generating Board.

SOME TECHNIQUES FOR THE EXAMINATION OF COMPLEX SPECTRA

L. BOVEY

Spectroscopy Group, Chemistry Division, Atomic Energy Research Establishment, Harwell

The problems arising in the study of the thousands of atomic lines emitted by rare earth and actinide elements when attempts are made to place these lines in an energy level diagram are discussed. The main technique to help the analysis is accurate measurement (over an extensive spectral range) of the lines given by special types of spectroscopic sources, and examined on high dispersion instruments; semi-automatic methods are important. Auxiliary information from such studies as Zeeman effect, hyperfine and isotopic structure are very useful. The use of computers is a powerful aid but the successful solution of the general problem requires a greater scientific effort than has been made in the post war years. An article by Dr Bovey on *The Interpretation of Complex Spectra* will be published in the November issue of *Research*. Reprints of the two articles can be obtained from Butterworths.

THE greatest attention to atomic spectroscopy (*i.e.* the study of light in the form of lines emitted or absorbed when there are transitions between the electron levels in an atom), took place in the years immediately preceding 1939. Verification of various physical theories and an interest in assigning the spectroscopic lines to the levels of the electron in the atom made the subject extremely popular among physicists.

In post war years there has been much less interest in the more academic side of spectroscopy but it has been used in many practical applications. The characteristic spectra of an element have been used for its identification in spectrochemical analysis. Study of the light emitted by stars or by plasmas has enabled many conclusions to be drawn about the state of matter emitting this light.

The derivation of the electronic structure of an atom from a consideration of the line spectra emitted is now studied only to a very minor extent, but it is true to say that most of the elements require further study since no spectrum is completely explained. The simplest spectra of hydrogen have recently been re-examined since from the Lamb–Retherford shifts occurring in the levels, important conclusions on the quantum-mechanical field theory can be made. The elements for which least is known about their spectra occur in the two groups known as the rare earths (lanthanum to lutetium) and the actinide (actinium to mendelevium) series. Elements in these groups give rise to extremely complex spectra and it is the purpose of this article to discuss some of the techniques for examining these.

Spectroscopic Problems of Rare Earths and Actinides

In any atom, there is the central core called the nucleus around which electrons are arranged in a definite order; these can be considered as arranged in groups of different energies and a line is emitted when an electron is displaced from one group to another. These groups or shells are denoted by numbers (1, 2, 3, 4 . . . *etc.*) and letters (*s*, *p*, *d*, *f*, *g*, *h*, *etc.*) the later letters showing a higher complexity in the electron shell. Atoms such as sodium with *s* and *p* shells give relatively simple spectra and only a few lines are emitted. For the more complex shells there are many possible energy values for the electron within the shell and these are called energy levels.

Many transitions between these levels are possible and therefore many more lines equivalent to the energy changes are emitted. Over ten thousand lines from uranium have been measured whereas sodium gives about one hundred. Lines emitted by a transfer of an electron from one level to another, have, as one of their chief properties, a frequency which is proportional to this energy change. This frequency determines where the line is emitted. In most experimental methods the wavelength in Ångströms (Å) is usually determined but this unit is easily converted to frequency units by a reciprocal relationship. A red line will be characterized by a frequency of about 15,000 cm^{-1} (6600 Å) whereas a violet line will be characterized by a frequency of about 25,000 cm^{-1} (4000 Å) (cm^{-1} is the spectrosopic unit by which frequencies are usually designated although multiplication by the velocity of light is necessary to convert to true frequencies).

The aim of the work is to assign the lines as transitions between levels and to obtain diagrams such as that for one of the rare earths (lutetium) shown as *Figure 1*. The most important level—the ground state—arises from a configuration of three electrons *d*, *s* and *s* (shown as 5*d*6*s*^{2}) and the strongest lines arise from transitions between upper levels and it. Some of the stronger and important lines are marked. A configuration containing *d*, *s* and *p* electrons (shown as 5*d*6*s*6*p*) gives rise to a large number of levels.

Figure 1. Diagram of energy levels and lines of one
of the rare earth elements—lutetium. The atomic
lines are shown as transitions between the energy
levels which are arranged relative to the lowest level
known as the ground state. The particular groups of
electrons giving rise to the energy levels are shown
as small letters. Only the important lines are noted
(KLINKENBERG[1]; courtesy Physica, 's Grav.)

The basic problems in spectroscopically examining
the lines are first to excite and produce them from
some convenient source, secondly to disperse this
light into its component lines and thirdly to measure

these. Auxiliary information such as whether the
line arises from the neutral atom or one in which
different numbers of electrons have been removed
(ionized atoms) is also required.

Sources

Most work in spectrochemistry uses a very simple form of source in which the material being examined is placed on one of two metal or carbon electrodes. A direct or alternating voltage is applied across these electrodes to produce the spectrum. This simple method, however, has several disadvantages. The lines emitted are usually quite wide and the process is not very controllable. Moreover, if the material is radioactive special precautions must be taken to contain the sample. In recent years, therefore, two forms of source have been preferentially used when it is important to examine and measure spectra accurately; these are known as hollow cathodes and microwave excited tubes.

In the hollow cathode the material under examination is dispersed on the inner surface of a small cylinder and this is used as the cathode in a discharge tube. A rare gas at a low pressure is also placed in the tube. A voltage of about 1000 V is applied between this cathode and an anode and an electrical discharge appears within the cathode. Light from this consists of very narrow lines. This source is used when such narrowness is particularly important.

One disadvantage of a hollow cathode is the low light intensity. In a second type of source, the material being examined is converted into its halide

and then placed together with an inert gas (usually neon) at 2–3 mm Hg pressure in a quartz tube. A convenient size is ½ cm diameter by 3 cm long. It is sealed off and placed in a high frequency field such as that given by a medical diathermy unit operating at 12 cm wavelength. The neon is first excited and as the temperature of the tube increases either by absorption of the microwave power or by some auxiliary heating, the spectrum of the halogen in both molecular and atomic form is seen. Finally, at a high enough temperature (in the case of uranium about 600° and for plutonium about 900°C) the spectrum of the metal is seen. It is very intense, consists of fine lines and is of constant intensity. The outstanding advantage is that since it is a sealed source in which only small quantities of the material need be used (micrograms in special cases) radioactive materials can be used without there being too great a hazard to the operator. The exact mechanism for the production of the spectrum is not understood but much modern work on complex spectra has involved the use of this type of source.

Several means of transferring the microwave power into a tube have been developed. One used at Harwell, shown in *Figure 2*, involves a cavity to which power is fed by a coaxial line from a magnetron oscillator.

Figure 2 (left). The cavity for the excitation of microwave sources. The microwave power is passed into the cavity from the lower connector. The tube containing the element is in the cavity and light is emitted through the aperture

Figure 3 (below). A section of the spectrum of two isotopes of plutonium together with spectra of iron and thorium which act as wavelength markers. The slight change in position of some of the plutonium lines (particularly at 3958·8 Å) given by the two isotopes is shown. The larger number of lines from the thorium and plutonium spectra relative to that of iron is evident.
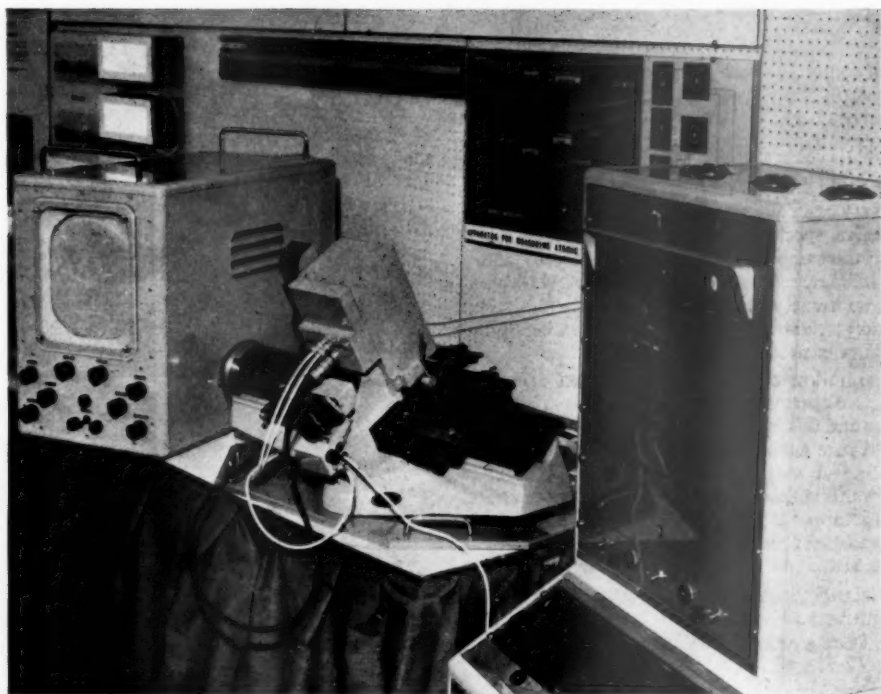*Both from BOVEY and WISE[2]; courtesy A.E.R.E.*

L. BOVEY
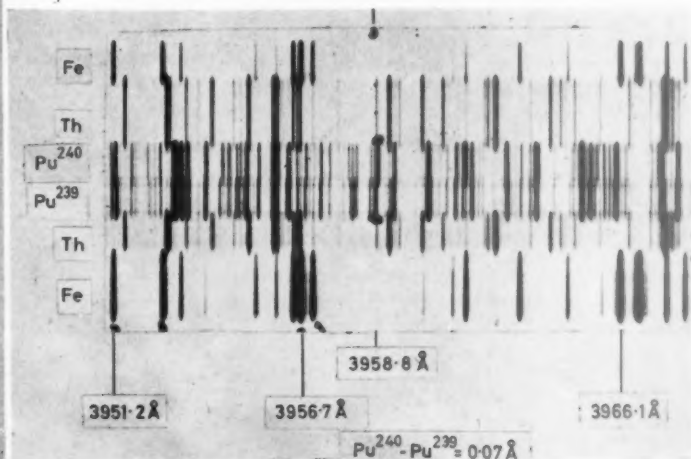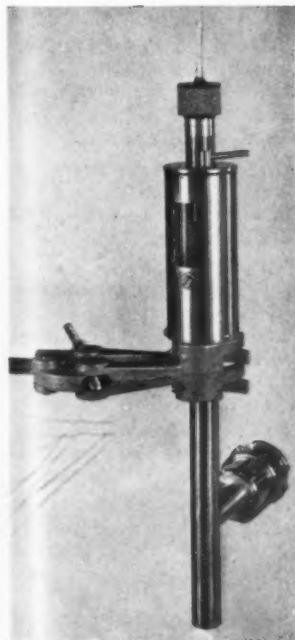
Figure 4. A general view of apparatus for the measurement of atomic spectra. On the right hand side is the electronic equipment used to count the moiré fringes so that the distance between lines along the plate can be measured; on the left hand side is the screen of the oscilloscope on which the trace of the lines is shown so that its centre can be judged. (Courtesy Hilger and Watts and A.E.R.E.)

Spectrographs

In order to examine these complex spectra it is necessary to spread the lines out as far as possible from one another both to distinguish one line from its neighbour and to give an accuracy of measurement as high as possible. The usual instrument for examining thousands of lines involves a grating. In post-war years, one outstanding advance in this field has been the commercial production of replicas of gratings so that there is a much greater availability of them. Both plane and concave gratings are now readily obtainable. With modern gratings and installations of extremely high precision it is now possible to determine the frequency of these lines to about 1 part in 10,000,000. As will be seen later on, this accuracy of frequency is extremely important.

Measurement

From these grating instruments are produced the photographic plates on which the lines have been recorded. A record of a short length of such a plate is shown in Figure 3. The grating spreads the light so that lines 1 cm^{-1} apart in frequency appear 0·4 mm apart on the plate. Lines from iron, thorium and two isotopes of plutonium are shown with certain of the iron lines marked with their known wavelength in Ångströms.

The major problem remaining is to measure such plates. The conventional method is to place the photographic plate on the carriage of a travelling microscope and measure the position of these lines by observation through the eyepiece, the data being recorded by hand. In view of the large number of lines this method suffers from two disadvantages; the first is the fatigue of viewing and the second involves the possibility of error in recording the data.

In order to reduce this eyestrain, techniques involving photomultipliers have been developed. In one important development the line is displayed simultaneously with its mirror image by a combination of electronics and optics on an oscilloscope screen. The viewer then arranges that the mirror

image and the direct image of the line coincide which ensures that the line is on a central datum position.

In order to reduce the amount of manual recording an automatic device can be attached to the screw which accurately indicates the position of the carriage on which the plate rests. Such devices (known as digitizers) allow the position of the screw to be electrically recorded; the data are then punched on either tapes or cards and further calculations can be made by computers. With a combination of these two techniques it is hoped that lines can be consistently measured to one part in ten million.

A further development of the method for recording the position of the line has involved the use of moiré fringes. When two gratings with the same number of rulings on each are placed nearly in contact with the rulings at a slight angle with one another, dark fringes (the moiré fringes) are seen. As one grating moves relative to the other, these fringes move at right angles to the direction of motion and their movement is directly proportional to the relative movement of the gratings. For application to the measurement of spectra, one grating is attached to the moving carriage and the other is on a fixed part of the instrument. The resultant fringes formed when the carriage moves can be detected by electrical means and therefore the motion of the photographic plate can be translated into electrical signals which are then fed into tape or cards, as in the digitizer. The gratings have been developed at the National Physical Laboratory, Teddington*, and are reasonably inexpensive. They offer a system which has several advantages over the screw; they should be more accurate than a screw and are cheaper to produce; there is also no effect such as backlash. An apparatus combining an oscilloscopic display of the line together with a moiré fringe system of measuring distances is shown

* See *Photographic Production of Gratings for Measurement* by Dr J. M. BURCH of the National Physical Laboratory. (*Research* (1960) XIII, 2)

in *Figure 4*. The line is displayed on the oscilloscope screen on the left and distances measured on the counters to the right of the travelling microscope. Movement of the carriage (with the plate) is recorded by moiré fringes formed between one grating mounted on the carriage and one fixed grating.

It is essential to have a standard spectrum with which the unknown spectrum can be compared. The frequency of the line in this spectrum should be known as accurately as possible and recent work has shown that thorium has many advantages over the conventional standard of iron. A recent advance in this subject has been an extensive study at the National Bureau of Standards, Washington, U.S.A., of the spectrum of thorium involving 5,000 lines and the measurement of these lines by accurate techniques.

The photographic recording of spectra is still the most accurate and useful method, but other ways of recording spectra are possible. In the visible region, a photomultiplier offers a very sensitive method and gives more accurate knowledge of the intensity of a line; special types of photomultipliers have been developed which are useful in the higher frequency end of the spectrum. Such detectors have not so far been applied to problems involving the wavelength measurement of complex spectra.

Infra-red Recording

At the lower frequency end of the spectrum the photographic plate becomes more and more insensitive until at frequencies below about 8000 cm^{-1} it cannot be used at all. In addition, the intensity of the lines decreases at the low frequency end of the spectrum. During the war, certain types of detectors which are sensitive at these low frequencies were improved. Such a detector is the lead sulphide cell which enables the spectrum range to be extended to about 3000 cm^{-1}. Apart from the

Figure 5. Photograph of the grating instrument used for the infra-red showing the grating (G), a slit (S) through which the light leaves the instrument and the mirrors (M) for directing the light on to the grating and detector. (BOVEY and STEERS[3]; courtesy A.E.R.E.)
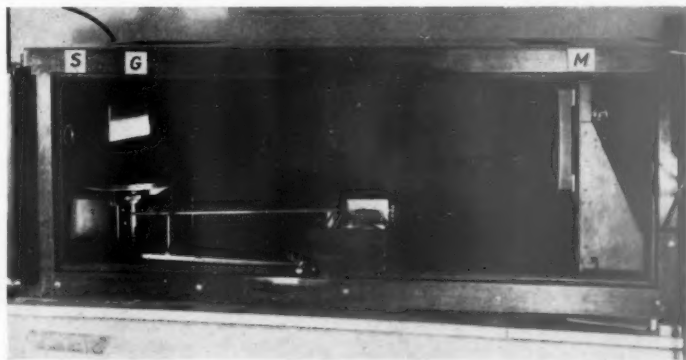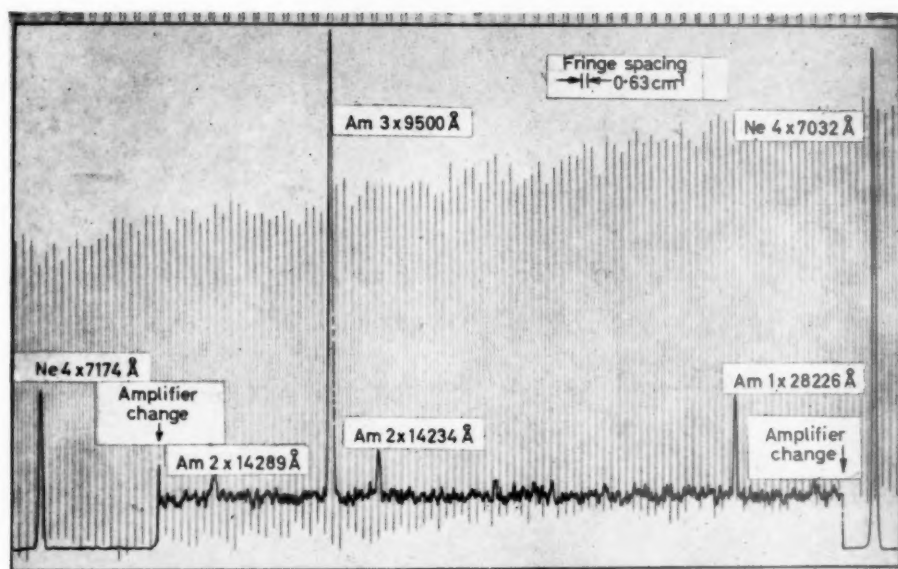
Figure 6. A typical record produced in the measurement of spectra in the infra-region. The lines of americium and the fringes from the Fabry-Perot plates are shown: fringes are calibrated relative to the two neon lines seen at each end of the chart. (BOVEY and STEERS[3]; courtesy A.E.R.E.)

advantages of having a wider region available, work at these lower frequencies should give more accurate values for the frequencies of the lines. Complex spectra have therefore been examined in this region with a lead sulphide cell as a detector. A grating instrument was used and the microwave source gave sufficient intensity for the lines to be detected. An instrument to record such spectra is shown in *Figure 5*. The light is diffracted at the grating (*G*) on to the mirror (*M*) and the lines recorded by a lead sulphide cell behind the slit (*S*).

It is not possible with this type of recording technique to compare directly the unknown spectra with the lines of a standard spectrum. A somewhat different technique is used in which interference fringes are simultaneously recorded; these arise when white light is passed through a pair of very flat plates held at a constant distance apart (Fabry–Perot plates). The fringes give a series of markers which are a constant frequency interval apart. By the insertion of lines of known frequency the fringes can be calibrated. These fringes are recorded simultaneously with the unknown infra-red lines on a two-pen recorder and direct comparison of the two traces allows the frequency of the unknown infra-red lines to be determined. A record of such a chart is shown in *Figure 6* in which the infra-red lines are

marked in Ångströms. The fringes run continuously across the chart and are calibrated by reference to the neon lines at either end.

Although such studies can be extended beyond the detection limit of the lead sulphide cell by use of other detectors, it would be necessary to produce different kinds of sources since those involving the use of quartz would not allow transmission of lines below its absorption limit at 2500 cm^{-1}. The main difficulty would be the low strength of the lines at lower frequencies.

Zeeman Studies

In addition to knowledge obtained from the frequency of the line, its behaviour in a magnetic field gives very valuable information on how the line arises in the atom and what levels are involved. When the source is placed in a field of about 30,000 oersteds (produced from a magnet such as that shown in *Figure 7*) the single lines are themselves split into a number of patterns; these patterns may in themselves consist of tens of lines which arise from the original single line.

With the development of the microwave excited sources it has been found possible to take these Zeeman patterns with less difficulty. The pattern shown in *Figure 8* was taken by microwave excitation

of a uranium source placed between the poles of the magnet shown in *Figure 7*. The lines were recorded on a grating spectrograph and a polarizer introduced so that light polarized parallel and perpendicular to the magnetic field was separately recorded. It should be noted that the presence of further components for each line causes many of the Zeeman patterns to overlap.

Effect of Nucleus

For many aspects of atomic spectra it is possible to neglect the influence of the nucleus. However, when detailed examination of lines is made, two important effects of the nucleus are found. The optical spectra from two isotopes, say U^{235} and U^{238}, are exactly similar in the number of lines since the electron configuration is the same in both cases, but there is a slight relative change in the frequency of some of the lines. Such an effect is known as an isotope shift. In uranium it can be as high as 1 cm^{-1} although in general somewhat smaller shifts are observed. These shifts are caused by the finite volume of the nucleus and subsequent interactions between the electronic and nuclear fields and give valuable information on the electron configuration connected with the line. It may also be noted that these shifts have a practical application. By quantitative observation of the intensity of certain lines arising from the two isotopes, the relative concentration can be found.

A second effect observed is that a line in certain of the isotopes actually consists of a number of components. Thus some U^{235} lines have seven components and some Pu^{239} lines have two components. This effect is also due to the interaction between the nucleus and the electrons, and is important from several points of view. The number of components gives the important nuclear property known as the spin, and in fact atomic spectroscopy is one of the main methods for determining it. The spacing and relative intensity of the components gives further information about the nuclear field and the electronic configuration respectively.

The examination of spectra to give this information on isotope shifts and hyperfine splitting requires special instruments and sources giving narrow lines. The instruments used must be able to give large separation of lines (high resolution and dispersion) so that these small differences between
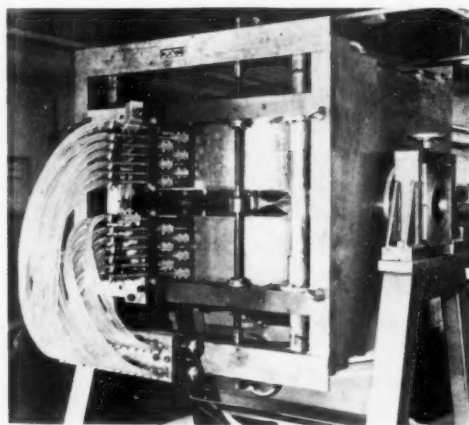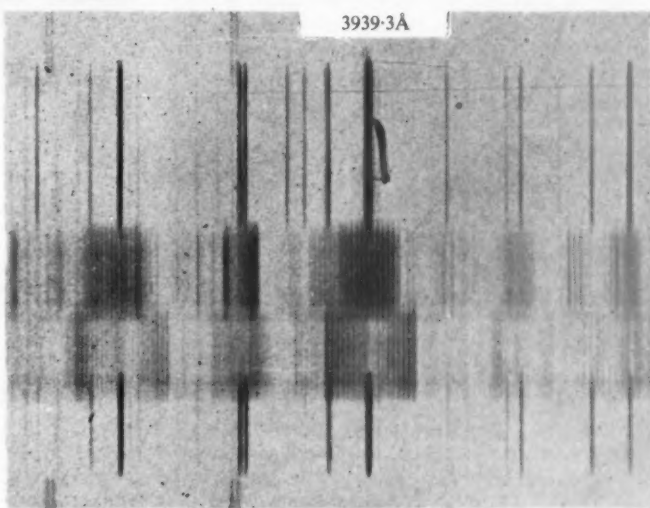

Figure 7 (above). A view of a magnet used in Zeeman work. The source is held between the poles, seen in the centre of the picture, and light is examined either through the hollow gimbals seen on the right, or directly from the front of the magnet. The tubes on the left hand side carry water for cooling the magnet. (Courtesy Associated Electrical Industries Limited, Manchester and A.E.R.E.)

Figure 8 (right). A typical pattern obtained in Zeeman spectra for uranium lines in the 3900 Å region. The single lines shown top and bottom produced when the field is not present gives rise to a large number of components seen in the centre of the photograph. The upper and lower parts show lines polarised parallel and perpendicular respectively to the magnetic field. The number and displacement of these components give very important information about the lines. (BOVEY and RIDGELEY[4]; courtesy A.E.R.E.)
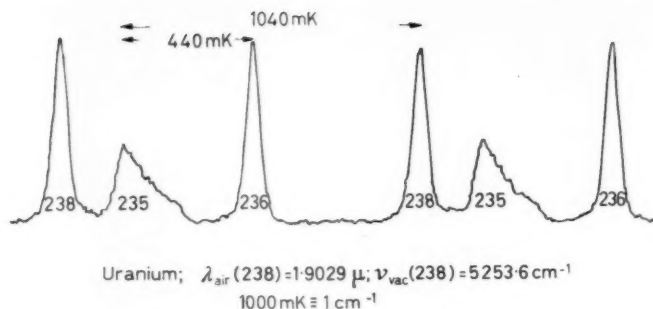

3939·3Å

Uranium; $\lambda_{air}(238) = 1\cdot9029\,\mu$; $\nu_{vac}(238) = 5253\cdot6\,cm^{-1}$

$1000\,mK \equiv 1\,cm^{-1}$

Figure 9 (left). The pattern represents the three lines from isotopes of uranium U^{235}, U^{236} and U^{238}. The much greater width of the U^{235} line is caused by the presence of hyperfine structure[5]

the components can be seen. Such instruments involve some form of interferometry and one of the post-war developments of technique has been in this field. When a line having components is passed through a pair of Fabry–Perot plates the components with their slightly different frequencies are separated if the resolution is high enough. The separation depends upon the refractive index of the gas between the plates and if this is varied the separation can be recorded as a function of this change in refractive index. A suitable method of doing this is to vary the pressure of the gas in the gap. Such a method is known as a pressure scanning technique and has been applied both in the visible and the infra-red regions.

Allied to this scanning technique has been a development in the special coatings put on the Fabry–Perot plates. The operation of the plates depends upon a large number of reflections at the two surfaces and if there is excessive absorption the efficiency of the Fabry–Perot is less. The successful application of dielectric coatings has increased the efficiency of the system and allowed successful determinations of the structure of various lines to be made. Studies of rare earth and actinide elements have been made with sources of both the hollow cathode and microwave excited types in the visible region. In recent months it has been found possible to extend this technique to the lower frequency range and figures are shown illustrating results from pressure scanning techniques.

The patterns shown in *Figure 9* arise from three isotopes of the uranium line at 5254 cm^{-1}. They were obtained from a microwave excited source containing the three isotopes U^{235}, U^{236} and U^{238} and the light was examined by a Fabry–Perot scanning technique. A large isotope shift of about 1040 mk (1000 mk = 1 cm^{-1}) between U^{235} and U^{238} is seen and unresolved hyperfine structure causes the extra width of the U^{235} line. Typical lines from Am^{241} examined by a similar technique are shown in

Americium^{241}; $\lambda_{air} = 1\cdot7271\,\mu$; $\nu_{vac} = 5789\cdot2\,cm^{-1}$

Americium^{241}; $\lambda_{air} = 1\cdot6379\,\mu$; $\nu_{vac} = 6103\cdot7\,cm^{-1}$
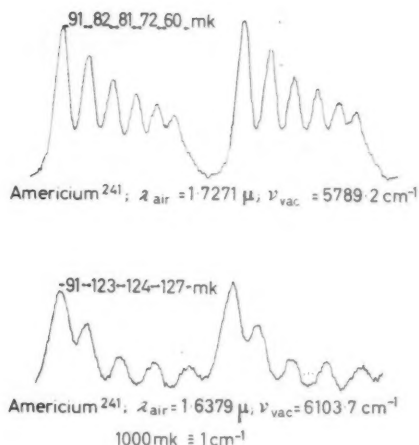
$1000\,mk \equiv 1\,cm^{-1}$

Figure 10. High resolution pictures of americium taken in the infra-red region showing the large number of components of some of these lines caused by the influence of the nuclear spin giving rise to hyperfine structure[5]

Figure 10. In the line at 5789 cm^{-1}, six components are seen and this result confirms that the nuclear spin of Am^{241} is 5/2. The complete number of components for the line at 6104 cm^{-1} is not given by the experiment.

Figure 11 was obtained by a similar technique but the line occurs in the visible region at 23,766 cm^{-1}. The two components of the hyperfine structure are seen 0·128 cm^{-1} apart and the line from a small amount of Pu^{240} (approx 1 per cent) in the sample of Pu^{239} is seen 0·07 cm^{-1} from one of the other components. Where the splitting is large it can also be seen on the grating instruments discussed earlier.

Computing Techniques

It can be seen that by these various experimental methods a large mass of data is assembled and the problem then arises of how to deal with it. Computers are of course used at every stage of the assembly of experimental data but it is likely that the main advantage of computers with their memory storage capacity, will lie in the final assembly and analysis of the data.
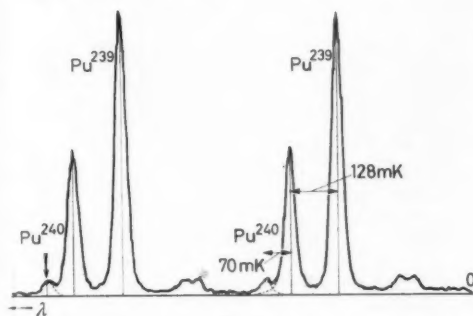

Figure 11. A high resolution picture of plutonium in which two components arise from the hyperfine structure. There is also a small component due to a second isotope of plutonium. In both this and the previous two figures the repeat patterns are a result of the method of taking the traces. (GERSTENKORN[6]; *courtesy Acad. Sci., Paris*)
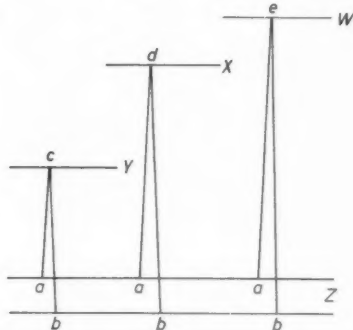

Figure 12. Diagram illustrating the sorting procedure used to find energy levels. Lines ca and cb, da and db, ea and eb arise from transitions between levels Y, X and W respectively and the common pair of levels Z. The frequency differences bc–ac, bd–ad and be–ae must therefore the be same. (BOVEY *and* NOTT[7]; *courtesy A.E.R.E.*)

One such application can take place immediately the frequencies of the lines have been measured. The basic principle behind the use of a machine in this case is illustrated by the following simplified example.

Some lines in the spectrum of an atom will arise from transitions between series of levels, say W, X and Y and another pair of lower levels Z; the energy values of the lower level will be the same in every case. Such a pair of levels necessitates pairs of lines whose differences must be equal; thus the differences in *Figure 12* between the frequencies of the lines *ca* and *cb*, *da* and *db*, *ea* and *eb* will be the same; hence one essential problem is to sort out these pairs of lines having the same differences. An application of such a technique is shown in *Table 1* where differences have been taken of the lines in the spectrum of lutetium. It will be noted that the difference 1994 occurs some 18 times and this is significant. (It is actually the difference for the lowest pair of levels arising from the configuration $5d6s^2$).

When several thousand lines are involved, as in the case of complex spectra, large numbers of possible differences are involved (equal to half the square of the number of lines). Sorting and subtracting can then be most profitably done with the aid of large scale computing equipment. Significant differences can in this way be found, but the main difficulty is still the large numbers involved and unless very accurate values for the frequencies of the lines are known a high number of misleading and coincidentally equal differences are found. Auxiliary information such as that from Zeeman effect, hyperfine structure and isotope shifts can allow some of these coincidences to be excluded, but the most important method in the analysis of complex spectra involves highly accurate frequency measurement.

Conclusion

It can be seen that modern techniques allow improved and more accurate knowledge of the spectra of these elements. In order to make rapid progress, however, data from all these studies are simultaneously required, and very few workers are at present engaged in this field. The only advantage of these small numbers is that collaboration between the various centres in which this work is carried on can be quite close. In America the main centres are the National Bureau of Standards, Washington, and various laboratories operated by the American Atomic Energy Commission such as Oak Ridge, Argonne and Los Alamos. In Europe the main centres are at the Bellevue Laboratories (France), the Zeeman Laboratory (Holland), Imperial College, London and the Atomic Energy Research Establishment, Harwell (England). In Russia similar studies are being followed both in Leningrad and Moscow. Some universities are also making studies on various aspects of atomic spectra.

The data from the results of term analysis are useful for problems in fundamental chemistry (*e.g.* ionization potentials) and physics (*e.g.* nuclear spin) spectroscopic properties of some twenty elements (many of importance in both nuclear and general technology) will then remain virtually unknown.

Table I. Differences arising from the spectrum of lutetium I. The numbers occur in sets of three: the first two represent the codes of the lines and the third is the difference with the decimal point between the fourth and fifth number omitted. Differences which lie within 0·2 of each other have been sorted into groups. It can be seen that there are 18 pairs which have a common difference of 1994 approximately. This difference actually corresponds to the splitting of the two levels seen in the first figure and arising from having the electron configuration 5d6s². (BOVEY, L. and NOTT, C. W.[7]; courtesy A.E.R.E.)

154 117	195338	176 158	195338	162 134	195351	188 169	195362
155 117	195402	226 221	195402	128 96	195406	189 169	195425
54 30	196807	219 210	196815	226 220	196824	46 22	196835
						227 221	196836
234 227	197950	252 246	197952	220 210	197966	226 219	197975
166 139	199381	116 92	199382	223 214	199383	234 226	199384
						84 65	199388
						221 210	199388
						240 235	199388
						204 181	199389
						215 201	199389
						217 206	199392
						244 237	199393
						88 75	199394
						120 94	199394
						172 153	199394
						55 31	199398
						52 29	199400
						137 99	199400
						227 219	199409
50 27	200213	153 116	200228	140 100	200229	70 52	200240
214 199	203623	208 186	203625	123 94	203626	150 112	203636
157 117	205449	191 170	205460	79 58	205464	209 186	205473
152 114	205912	72 55	205925	215 200	205926	14 109	205939
						466 20	205945

as well as the more practical applications such as spectrochemistry and isotopic analysis. The results have important applications in crystal chemistry. It should be noted that much of the current work on the study of light emitted by plasmas is based on term analysis of the simpler elements mainly carried out at the time by academic spectroscopists disinterested in practical applications.

With so few workers, more emphasis should probably be placed on encouraging these to move more between laboratories (where special techniques have been developed) rather than for each to build equipment similar to that in use elsewhere. This would be a more efficient way of accumulating data although it does create personal problems for the scientist.

Unless, however, a concentrated effort on the analysis of complex spectra can be made it seems that in spite of the development of very powerful techniques progress may be extremely slow. The

References

[1] KLINKENBERG, P. F. A. *Physica, 's Grav.* (1955) **21**, 53
[2] BOVEY, L. and WISE, H. *A.E.R.E. Rep. C/R 2976*, 1959
[3] BOVEY, L. and STEERS, E. B. M. *A.E.R.E. Rep. C/R 2827*, 1959
[4] BOVEY, L. and RIDGELEY, A. *A.E.R.E. Rep. R3393*, 1960
[5] BEER, R. and BOVEY, L. *Proc. phys. Soc., Lond.* 1960 (in press)
[6] GERSTENKORN, S. *C.R. Acad. Sci., Paris* (1960) **250**, 825
[7] BOVEY, L. and NOTT, C. W. *A.E.R.E. Report C/R 1334*, 1954

SURVEY

Warren Spring Laboratory

Fischer-Tropsch Process

Instead of the ' coal is gold ' attitude of the war-time and post-war years, one of the problems of the National Coal Board is the disposal of growing stocks of low grade coal. A potential use is to react
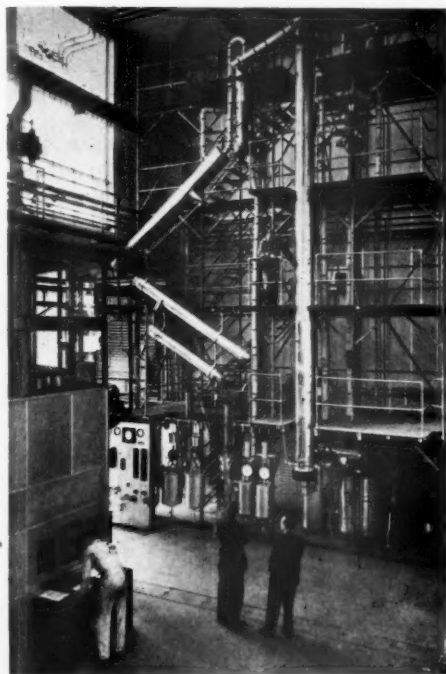

Figure 1. Fischer-Tropsch pilot plant. (Courtesy The Controller, H.M.S.O.)

CO and H_2 produced from this coal to synthesize hydrocarbons—gas, liquids or waxes (the Fischer-Tropsch process). During the war Germany used this process to produce town gas, chemicals and oil and since the war Lurgi pressure-gasification plants have been built in South Africa and Great Britain (*Research* (1958) **XI**, 157 and (1959) **XII**, 136).

However, although the synthesis of liquid hydrocarbon fuels at present proves uneconomical, the Warren Spring laboratory, Stevenage, successor to the disbanded Fuel Research Station at Greenwich,

is trying to improve efficiency and reduce costs. A pilot plant (*Figure 1*) is used to investigate production of hydrocarbons under different conditions of temperature and pressure. The length of the hydrocarbon chain, and therefore the type of product, whether gas, liquid or wax, is mainly determined by the temperature at which the reaction takes place and it is thus of the utmost importance that the temperature should be kept constant to within 1°C. The temperature of the reaction is in the range 200°–300°C at a pressure of 10–20 atmospheres and therefore a highly efficient cooling system is a very vital part of the equipment.

The catalyst used is also the object of intensive research. Iron oxide has been found to be the most effective one and its action under different physical conditions is tested. Addition of small amounts of other compounds such as titanium dioxide has been found to speed up the reaction and research is going on into the relationship between electrical and catalytic properties.

Mineral Processing

During the recent meeting in Great Britain of the British Commonwealth Scientific Committee, a Commonwealth Committee on Mineral Processing was formed. This committee will be centred in England and will be in close touch with Warren Spring where there is a large mineral processing laboratory, operating mainly on a repayment basis. Sample pieces of ore are sent here from all over the Commonwealth for analysis and for advice on the best method of separating the minerals. Various separating methods are used, for example, flotation, gravity separation, magnetic separation and leaching.

Warren Spring is the youngest of the D.S.I.R. laboratories, and these are but two projects in an interesting and diverse research programme.

Emission Microscope

The Royal Dutch/Shell Group are also interested in catalysis, and fundamental research into this phenomenon has been going on in their Amsterdam laboratories for years. An emission microscope is being used to study the mechanism of adsorption on the crystal faces of a catalyst and the nature of the interaction between the adsorbed molecules and the catalyst surface.

In *Figure 2* photographs of the image of a tungsten crystal on the screen of an emission microscope show the effect of atoms adsorbed on the surface
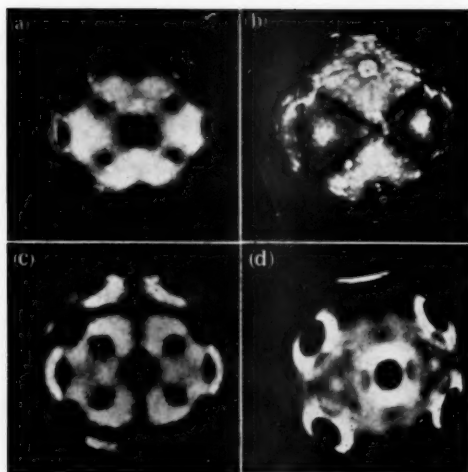
Figure 2. Emission microphotographs illustrating the adsorption of ions on a catalyst surface. For explanation see text. (Courtesy Shell)

Astrobotany

The recent excursions into space have stimulated the imagination of scientists, novelists and lunatics, and our neighbours Mars and Venus, and even the more remote planets, have been credited with a diversity of live inhabitants. In spite of the multiplicity of space vehicles earth-bound astronomers, using mundane techniques, still make a contribution, and the new science of *astrobotany* is based on the comparison of properties of terrestrial plants with similar phenomena exhibited by the planets.

The late Professor TIKHOV, the Russian astronomer, demonstrated that the 'seas' or bluish areas on Mars could be patches of some hardy vegetation, capable of existing under extremely severe conditions. He did this by comparing the spectra of the Martian seas with those of terrestrial plants; after periods of intense cold terrestrial plants such as conifers and even some leafed plants absorb solar energy not only in the infra-red range but also in the red and even the yellow-green, and their spectral properties are very similar to the Martian seas. Tikhov concluded that plants on Mars absorb all rays but reflect only violet and blue ones—hence their colour. In 1958 SINTON, the American astrophysicist, added to the evidence of life on Mars by demonstrating that in the infra-red range there are dark lines similar to those lines in the spectra of terrestrial plants which indicate the presence of organic matter.

Tikhov went even further and maintained that it is possible that there is life not only on Mars and Venus but also on Jupiter and Saturn, as he found similarities between spectra obtained from these planets and the spectrum of 'organic' methane or methane produced by the decay of organic matter.

of the metal. *Figure 2(a)* shows the clean surface of the metal and in *2(b)* the surface is covered with positively charged ions. The individual bright spots represent groups of four to six ions, causing a strong local increase of the electron emission. *Figures 2(c)* and *(d)* show the reorientation which occurs with increased temperatures: in *2(c)* the temperature was 200°C and the ions have moved to those places where the gain in energy is largest; *2(d)* shows the complete reorientation and new symmetry when the temperature is increased to 450°C.

Figure 3. Planisphere of Mars. (Courtesy Académie des Sciences, Paris and UNESCO)

BOOK REVIEWS

Energy Principles in Applied Statics

T. M. CHARLTON

(*vii + 112 pp; 9¼ in. by 6¼ in.*)

London: Blackie & Sons. 25*s*

IN HIS preface the author states that his purpose is to attempt to remove some of the confusion which exists among students and engineers concerning the nature and use of energy principles in applied statics. He has not only succeeded in this but also in writing a most scholarly account of work in this field.

In these days when books and papers written by specialist authors frequently display a maximum of mathematics and a minimum of text, the reader must have a fairly wide background if he is to grasp the general philosophy behind the working details. This book is sound pedagogy; and although difficulties are by no means dodged, the author's gift of exposition appears to make light of them—and even the experts do not cavil at having all made abundantly clear!

After a simple introduction to energy methods and the conception of complementary energy in the first chapter, equilibrium conditions by methods of strain and potential energy are discussed in Chapter II, with an application to statically indeterminate and non-linear systems. Further well chosen detailed examples follow in Chapter III. A detailed discussion of the principle and scope of virtual work and complementary energy methods occupies the next two chapters, with further examples of complementary energy application in Chapter VI. The final chapter is devoted to the use of flexibility coefficients and related topics. The author eschews matrices which are required for a treatment of the overall system flexibility, perhaps wisely in a book of this intention.

There is a well selected and sufficiently comprehensive bibliography which does not ignore the classics of the last century—papers by Maxwell, Rayleigh, Castigliano, Engesser and Betti.

The book is very well produced and a pleasure to handle: the type is graceful and easily read, and the figures are very clear. It may be recommended both to the student and the practising engineer.   A.M.H.

Advances in Organic Chemistry: Methods and Results. Volume I

R. A. RAPHAEL, E. C. TAYLOR and H. WYNBERG (*Eds*)

(*ix + 387 pp; 9¼ in. by 6 in.*)

New York and London: Interscience Publishers. 90*s*

Two questions are to be asked about this book. First, is the series of which it forms Volume I necessary? Second, is the book itself necessary?

The answer to the first question is 'No!' Unless the series develops a quite individual character as it grows, it is impossible to see any purpose which it serves which is not already well served by 'Organic Reactions', by COOKS 'Progress in Organic Chemistry', and by 'Chemical Reviews'. One can only conclude that there

is money to be made in the publishing of such a series of books. Presumably, libraries feel a compulsive necessity to buy all such publications, for it is unlikely that more than a few individual purchasers will be found.

The answer to the second question is more complicated, for whilst it is true that, to the reviewer's knowledge, at least four of the six topics in this volume have been reviewed before in the recent past, these essays are all of high quality and of general interest. The topics dealt with are 'The Kolbe Electrolytic Synthesis' (B. C. L. WEEDON), 'Polyphosphoric Acid as a Reagent in Organic Chemistry' (F. UHLIG and H. R. SNYDER), 'The Wittig Reaction' (S. TRIPPETT), 'Hydroxylation Methods' (F. D. GUNSTONE), 'The Selective Degradation of Proteins' (E. O. P. THOMPSON), and 'Optical Rotary Dispersion and the Study of Organic Structures' (W. KLYNE). It might even be argued that the intense and widespread interest in the subject of Klyne's article justify the publication of this volume as a sort of poor man's 'Djerassi'.   K.S.

Eye, Film and Camera in Color Photography

R. M. EVANS

(*xii + 410 pp; 9¼ in. by 6 in.*)

New York: John Wiley; London: Chapman & Hall. 72*s*

WHAT an observer sees when looking at a scene, and what he sees when looking at a photograph of the same scene are usually very different, even when modern optical equipment and colour processes are used. Yet the observer may be entirely unaware of many of the differences, and may consider the photograph to be an 'accurate' reproduction of the original scene. Some of the geometrical distortions inevitable in reproducing three-dimensional subjects as two-dimensional images, and some of the consequences of the inadequacies of the available photographic processes are quite widely known. Less widely recognized, but probably much more important are the physiological and psychological mechanisms which may exaggerate or diminish the consequences of differences in perspective, contrast or colour balance between the original scene and the photograph, and which also make it possible for the appearance of a colour photograph to remain acceptable despite considerable changes in the colour and brightness of the light by which it is viewed.

In 'Eye, Film and Camera in Color Photography' the author examines these phenomena in detail, with a large number of black-and-white photographs to illustrate the various effects. Many of the photographs are in pairs to show the consequences of changes in lighting, contrast or some other circumstance. The text is divided into ten chapters of which the most important are 'How we see things' and 'The perception of light and color in photographs', in which the various psychological and physiological effects are described. Rather more than a quarter of the book consists of two chapters describing the control and exploitation of these effects and of the particular characteristics of the photographic processes.

The book is written in a difficult and uninteresting style which detracts from the value of the excellent photographs, and a serious study of the book soon becomes laborious instead of enjoyable. The text and the illustrations are not always sufficiently closely related, and several of the photographs show optical distortions which are inadequately described in the text. The description of the optical principles of photography is not easy to follow and will probably confuse readers who have little previous knowledge of photographic optics. However, despite these shortcomings, there is a great deal of value in this book for photographers using either colour or black-and-white processes. The presentation and printing of the book are excellent, but the price is rather high.   H.N.D.

Gmelins Handbuch der Anorgischen Chemie (8th Edition)
Silicon (Vol. 15, Part B);
Strontium (Vol. 29, Supplement to 1931 volume);
Barium (Vol. 30, Supplement to 1925 volume);
Cadmium (Vol. 33, Supplement to 1925 volume);
Oxygen (Vol. 3, Section 4, 1960);
Alphabetic–Subject Index

(lix + 923 pp; xxx + 306 pp; xlv + 569pp; xciv + 802 pp; xvi + 366 pp; 109 pp. 10 in. by 7 in.)

Weinheim: Verlag Chemie DM 570, 195, 354, 508, 223, 30

THE above new volumes to the 8th edition of the giant bibliography, *Gmelins Handbuch*, have recently been published. Part C of the trilogy on Silicon was published in 1958 (*Research* (1959) **XII**, 161) and was devoted to organo-silicon compounds. The new volume, part B, is in two sections, covering the literature up to the end of 1949 referring to elemental silicon and silicon compounds. (Part A, on the occurrence of silicon, is not yet published.)

The three supplementary volumes on Strontium, Barium and Cadmium follow the usual pattern of the series, with sections on history, occurrence, metallurgy, technology, properties, analysis, alloys and compounds, bringing the earlier editions up to date to the end of 1949. The contents lists are printed in German and English, and English translations of the section titles are printed in the margin beside the section in question. Page numbers of comparable sections in the parent volumes are given in the contents lists of the supplements.

Section 4 of the five-part volume on Oxygen has chapters on Air, Active Oxygen and Ozone. The first covers the physical properties of air (the electrochemical behaviour was dealt with in Section 3 and chemical reactions in the volumes on the reaction partners). In the chapter on Active (Atomic) Oxygen the formation and preparation, phosphorescence spectrum and chemical reactions are covered; the chapter devoted to Ozone is the longest and deals with preparation, physical properties, electrochemical behaviour, chemical reactions, and aqueous and non-aqueous solutions. The first three sections on Oxygen were published in 1953, 1951 and 1958 and a fifth section will follow in 1962; all covering literature to the end of 1949.

The classification system used by Gmelin Institute was published as *Systematic Subject Index* in 1957, indexing all the terms required in logical order. The new *Alphabetic–Subject Index* is a supplement to the Systematic Index and the two are correlated by use of code numbers. The index is printed in English and German.   R.A.D.

Microscopic Sedimentary Petrography
(vii + 485 pp; 9¼ in. by 6 in.)
ALBERT V. CAROZZI

New York: John Wiley; London: Chapman & Hall. 92*s*

THIS book is concerned with the characters of sedimentary rocks that are revealed by the study of thin sections under the microscope. This needs to be said because of the peculiar usage of words in the title, which should have been *The Micropetrography of Sedimentary Rocks*. Similar unusual English is characteristic of the whole book and is referred to again below. The book is not concerned with determinitive microscopy but with the description and interpretation of the textures, grain structure and mineral composition of the rocks. There is no other book covering this field, which is one of great interest, and it is therefore very welcome.

The greater part of the book consists essentially of abstracts of original papers published in a great variety of European and American journals and most of the illustrations are reproductions of illustrations from these papers. The author's main contribution has been the selection and grouping together of these abstracts—and for this research workers will be grateful. His claim to have presented a series of pictures of ' ideal ' rock types will certainly be disputed by some, who will feel also that his use of the word ' typical ' in connection with many particular examples and the word ' usually ' in relation to certain characters of his ' ideal ' rock types cannot be justified. It is a stimulating rather than authoritative work. For this reason, and because many familiar terms are used in a very individual way and will be misunderstood by any but the expert, this is not a book to be recommended except to trained sedimentary petrologists.

Finally it must be said that the book is written in rather imperfect English. This is perhaps in part because it is an American publication and such words as ' desertic ', 'echinodermic', 'percellaneous', 'expulse', 'indetermined' may not offend the American, as they do the English ear. But there are many words which are simply used—as ' realized ' for ' developed ', and ' matters ' for ' substances ', and sentence construction is often at fault. However the sense is usually clear to an expert reader.

The use of ' oolite ' for ' oolith ' or ' ooid ' is not an error; but it is the continuation of a highly undesirable practice which has nothing to commend it and can only cause confusion. This is a glaring example of wanton disregard of established usage for no good reason, and an emphatic protest is called for.   'S.S.